LIMESTONES

OF

PENNSYLVANIA

BENJAMIN LEROY MILLER

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Limestones of Pennsylvania

By

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Harrisburg, Pa.
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LETTER OF TRANSMITTAL

Hon. Philip H. Dewey
Secretary of Internal Affairs
Harrisburg, Pennsylvania

My dear Sir:

I am transmitting herewith the text, maps and illustrations for a detailed report on the Limestones of Pennsylvania.

This is the second edition greatly enlarged from the first edition of this report. The first edition was destroyed by fire and information on the limestones of the State continues to be in demand. The present edition, because of the inclusion of much material not found in the first edition, should be very valuable. In addition, the material has been arranged by counties, which it is thought will add greatly to its usefulness.

Because of the large number of limestone quarries it is not possible for an author to visit all of them in one summer. Nor is it possible for a college professor to write so voluminous a report as this in his spare time during one college year. Furthermore, this report was transmitted in 1932 but not printed then because of inadequate funds. This explains why the latest references to quarry and plant conditions, product, etc., are more than three years old at this date.

Respectfully submitted,

Geo. H. Ashley

State Geologist.

May 5, 1933

PREFACE

In 1925 the Topographic and Geologic Survey of Pennsylvania published *Limestones of Pennsylvania,* Bulletin M-7, in response to numerous inquiries concerning the limestone resources of the State. The edition was partially distributed when a fire in the building occupied by the Division of Documents destroyed the remaining copies. Since that time requests for copies have continued to be received. It was therefore decided to issue a revised edition and the present volume is the result. In preparation for the revision, most of the important limestone regions of the State were revisited by the writer and much new data assembled. The present volume is approximately double the size of the original issue, and it is hoped that it may be correspondingly more useful.

The primary purpose of this volume is to furnish information concerning the limestones of the State to those persons or firms that are interested in their utilization. Although the stratigraphy of the different sections received attention, the report does not purport to furnish all the available results of the stratigraphic investigations dealing with the limestones that have long been carried on within the State. The intention has been to include only as much stratigraphic material as necessary for an appreciation of the economic situation. Any other plan would have unduly increased the size of the volume.

The writer has drawn freely upon the published and manuscript reports of other geologists, especially the members of the present Geological Survey. Where recent investigations have been made by other workers, the writer has economized in time, which was limited, and has only made sufficient examinations to furnish him with the necessary background for compilation of the existing data.

No general report of this character on the limestones of the entire State of Pennsylvania can be regarded as complete because of the thousands of limestone quarries that have been operated at various times. It would manifestly be impracticable to attempt to describe every quarry. It is hoped that enough descriptions have been included to furnish the reader with the general characteristics of each limestone area.

The writer wishes to thank the numerous individuals and firms that have rendered assistance in the collection of data. Without exception he has received uniform courtesy from all the operators visited. Maps, analyses, and production data have been freely given. Specimens have been analyzed without charge in many cases, especially by the Valley Forge Cement Company, to whom the writer is particularly indebted for analyses of various limestones illustrating origin and weathering peculiarities.

In the field work assistance has been rendered by Dr. Lloyd W. Fisher, Dr. Bradford Willard, B. Frank Buie, Ralph L. Miller, William B. Whittock, Kenneth R. Eckrote, and a number of other former Lehigh University students.

For assistance in the preparation of the report for publication, the writer desires to thank the various members of the Survey, especially Dr. George H. Ashley, State Geologist, R. W. Stone, Assistant State Geologist, Dr. Bradford Willard, Charles K. Graber and Wm. O. Hickok, 4th. The county maps have all been drawn by Miss Marie M. Johnstone.

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CHAPTER I

COMPOSITION OF LIMESTONE

A limestone may be defined as a sedimentary rock, normally white to light gray or buff in color, composed primarily of calcium carbonate ($CaCO_3$) and occurring in beds or strata of considerable areal extent. The individual beds are fairly uniform in composition.

CHEMICAL COMPOSITION

From the normal type, there are all sorts of variations and in places limestones pass almost insensibly by gradation into shales or sandstones. One of the limestones (Loyalhanna) described on later pages of this volume might properly be termed a calcareous sandstone, because of its large content of siliceous grains. Some so-called limestones contain such a large amount of clay that they might appropriately be called calcareous shales. No one has attempted arbitrarily to draw the lines separating the various classes of sediments. Instead it is customary to use adjectives to describe the intermediate products. Thus we have siliceous limestones or calcareous sandstones and argillaceous limestones or calcareous shales. In addition, limestones containing abnormally large percentages of iron, phosphate, carbonaceous matter, and magnesia are described respectively as ferruginous, phosphatic, carbonaceous, and magnesian limestones. In some cases, the addition of ingredients other than calcium carbonate tends to make the limestones less valuable but in other cases the addition of foreign matter renders them more useful for particular purposes.

A pure limestone should contain 100 per cent of $CaCO_3$ and in certain places in Pennsylvania and elsewhere there are limestones that approximate this composition. Generally, however, there is at least 2 or 3 per cent of other material in even our best limestones. One would expect this situation since practically all our limestones have been laid down in shallow ocean waters in which there are almost invariably other substances in solution and in suspension, and some of these precipitated on the ocean bottom are apt to be mixed with the calcareous matter.

Limestones are used in a great variety of ways, as will be described on later pages. For most of these uses a particular chemical composition is either requisite or preferable. This means that chemical analyses must be made and as a result great numbers of analyses are available and more are rapidly accumulating. Seldom, however, are the analyses complete, as it is not important to determine the presence of those elements that may be present in such minute quantities as to have no bearing on their economic utilization. It seems certain that careful analytical investigations of limestones would reveal the

presence of many chemical materials not thus far determined. Most of the analyses given in this volume have been obtained from manufacturing companies using limestones in which a fairly definite composition is necessary. Many of these companies employ chemists as regular members of their organizations. This is particularly true of the cement and steel companies. In a number of cases the analyses have been obtained from the dealers in limestone who have employed chemists to analyze their product in order to learn the particular uses for which it is fitted.

In analyzing limestone, the substances usually determined are calcium oxide (CaO) or calcium carbonate ($CaCO_3$), magnesium oxide (MgO) or magnesium carbonate ($MgCO_3$), carbon dioxide (CO_2), silica (SiO_2), aluminum oxide (Al_2O_3), ferric oxide (Fe_2O_3), ferrous oxide (FeO), sulphur (S), sulphur dioxide (SO_2), sulphur trioxide (SO_3), phosphorus (P) or phosphorus pentoxide (P_2O_5), calcium sulphide (CaS), strontium oxide (SrO), hydrogen sulphide (H_2S), and water (H_2O), For individual purposes the analysis will not show nearly all of these. For example, a steel company may determine only the amount of silica and a cement company rarely determines other than the calcium, magnesium, silicon, iron, and aluminum compounds.

The substances occasionally determined are manganese dioxide (MnO_2), titanium oxide (TiO_2), carbon (C), sodium oxide (Na_2O), and potassium oxide (K_2O).

It is recognized that all of these substances may and do vary widely in the amount present. It is not possible to state the limits definitely but in general the following ranges are believed to be approximately correct. The CaO is apt to vary from 22 per cent in some of the Loyalhanna limestones to approximately 56 per cent in some of the purest limestones of the State. These correspond to 39.29 and 100 per cent of $CaCO_3$. The MgO content may vary from 0 to 21.43 per cent. This corresponds to 0 to 45 per cent of $MgCO_3$. In a few cases the magnesium has been reported as even higher, which probably means that some is present uncombined with calcium carbonate. Some analyses of this kind known to the author, however, are regarded as of questionable accuracy.

The Al_2O_3 varies from 0 in the pure limestones to as much as 5 or 6 per cent in the argillaceous limestones used for the manufacture of Portland cement. By a still further increase of Al_2O_3 and a corresponding decrease in $CaCO_3$ the rock becomes calcareous shale and is no longer appropriately called a limestone.

The Fe_2O_3 and FeO range up to several per cent in some of the ferruginous limestones. Seldom do the iron oxides exceed 3 or 4 per cent. However, in western Pennsylvania the Vanport limestone has been changed to siderite by replacement and all gradations can be found from high grade limestone ($CaCO_3$) to siderite ($FeCO_3$). When the siderite undergoes oxidation, as it does readily, the resulting material is practically pure iron oxide. Locally limestones are found unusually high in pyrite. On analysis, the iron is apt to be reported as oxide and may be higher than given above. Any limestone with more than 1 or 2 per cent of iron oxide is apt to become brown or red on oxidation by exposure to the air.

The silica content in limestone is very important for many industries using limestone. It is determined in almost every limestone analysis

and may be said to be present almost universally. In many of the purest limestones it constitutes much less than 1 per cent. It probably averages from 3 to 6 per cent, more in the dolomitic limestones than in the low magnesium varieties. In the most siliceous limestone of the State, the Loyalhanna, silica constitutes about 50 per cent of the stone. In certain places the Loyalhanna passes by gradation into a true sandstone in which the silica constitutes practically the entire composition.

Sulphur (S) is frequently noted in chemical analyses of limestones and occasionally it is reported as SO_2 or SO_3. It is unusual to find more than 1 or 2 per cent of sulphur present and generally it is much less than 1 per cent. The sulphur present, although generally reported as uncombined, is almost altogether in combination as sulphides, principally pyrite (FeS_2) or marcasite (FeS_2), or as sulphates such as gypsum ($CaSO_4.2H_2O$) or strontium sulphate ($SrSO_4$).

Phosphorus, reported as P or as P_2O_5, is generally negligible in limestones although commonly present in extremely small amounts. It is generally regarded as objectionable but the permissible amounts have not been satisfactorily determined. Its effect in fluxing stone is known, but not in the manufacture of Portland cement and other manufactured products. No limestones are known within Pennsylvania where the phosphorus content is great enough to need to be considered. Some unaltered limestones in Kentucky and Tennessee contain from 2 to 6 per cent of P_2O_5, according to report. One cement company is said to have had difficulty in producing a satisfactory grade of Portland cement because of the large amount of phosphorus in the stone used.

The water content of limestones is extremely variable. In most cases the analyses are reported as water free.

The amount of carbon present varies greatly. It may occur in sufficient amount to make the limestone black, yet because of the ease with which it is oxidized and eliminated in manufacturing plants, it is seldom determined even though it may constitute several per cent of the stone.

The other constituents of limestones are almost invariably present in such small amounts, fractions of one per cent, that there is little occasion to regard them, and their presence does not affect the utilization of the stone.

MINERALOGICAL COMPOSITION

The chemical composition of a stone does not necessarily indicate the particular minerals present. The minerals are definite compounds and some of the chemical elements and combinations as reported in chemical analyses may enter into several different minerals. For example, the silica may and, in most cases, does exist mainly as quartz, which is pure silica, but in addition part of it is combined into various silicate minerals; sulphur may be present uncombined, but in almost all cases is united with iron to form pyrite or marcasite, with some other metals to form other sulphides, or with metals and oxygen to form sulphate minerals. In a similar way almost every substance determined by the chemist may enter into combination with other material to form a number of different minerals.

The desirability of a particular stone may depend upon the minerals present and in many instances may not be determined by the

chemical analysis. An illustration is furnished by pyrite and marcasite, both with the same composition (FeS_2) and yet with many different properties. On exposure to moist air both will oxidize to form iron oxides and sulphuric acid but with different rapidity. Marcasite will decompose very quickly and a stone containing a large amount may crumble in a short time because of this action, whereas pyrite undergoes such a change very slowly in comparison. Other illustrations might be presented to show the importance of knowing the mineralogical composition of a stone as well as its chemical constitution.

A great variety of minerals has been reported as occurring in limestones. The list which follows is not claimed to be complete but it doubtless includes most of the minerals thus far recognized. Of these calcite is the only essential mineral of pure limestone, and calcite and dolomite the only essential ones forming dolomitic limestones.

Methods for distinguishing calcite and dolomite. It is frequently useful to determine whether a limestone is composed mainly of calcite or dolomite and if possible to do so in the field. As the chemical analysis of limestone is expensive and requires time, attempts have been made to locate stone of the required kind with a minimum of chemical analyses. Considerable progress has been made, although most geologists feel that they must check their field determinations by occasional analyses. Several methods are in common use.

If dolomite is present in large amounts, one can frequently approximate the amount by the weight when balanced in the hand, as dolomite is slightly heavier than calcite. Of course, this method requires experience and at best is a rough determination.

The color is apt to be suggestive in the case of those materials low in iron and carbonaceous matter. The more highly magnesian limestones will show a light buff tinge whereas the low magnesian varieties will be white or bluish-gray. On weathering, however, the dolomitic layers become chalk white, considerably whiter than the low magnesian strata.

The different degrees of solubility are more reliable in that calcite dissolves fairly readily in cold dilute hydrochloric or acetic acid and produces vigorous effervescence while dolomite dissolves and effervesces very slowly in comparison. However, if the dolomite is pulverized by the blow of the hammer or if the rock is feebly cemented and hence porous this test is not serviceable in that the effervescence may be almost as rapid and vigorous as in the case of low magnesian rocks.

Steidtmann* describes some other methods that have come into rather common use.

"For a more delicate distinction of dolomite and calcite when dealing with intimate mixtures of the two, several methods have been used, of which three will be described. Calcite and dolomite can usually be distinguished by polishing a surface of the rock and etching it with a weak solution of muriatic acid. The proportion of one acid to ten of water previously recommended will do very well. In the course of a few hours, the dolomite grains will stand out in relief above the etched calcite. Those dolomite grains which are completely surrounded by calcite have rhombic outlines, but those bounded by other

*Steidtmann, Edward, Limestones and marls of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 66, pp. 7-8, Madison, 1924.

dolomite grains are generally irregular in outline. A modification of this method consists in adding a little potassium ferricyanide solution to the acid. The calcite will show no change as a rule, but the dolomite, unless very much weathered, will almost invariably turn blue, due to the presence of a minute amount of ferrous iron in combination with the dolomite. Dolomite grains stained in this way retain their blue color for many years. In hundreds of tests made by the writer, the calcite in no case was stained, but the dolomite was stained every time.

"Calcite can also be distinguished from dolomite by staining the calcite. In this method the rock is polished and treated with Lemberg solution. The proportions giving best results appear to be 4 grams $AlCl_3$, 6 grams extract of logwood, and 1200 grams of water. The mixture is boiled and stirred for twenty minutes and then filtered. The $AlCl_3$ of the solution interacts with calcite particles and causes a thin film of $Al(OH)_3$ to be deposited upon the calcite. The $Al(OH)_3$ is gelatinous and absorbs the purple colored extract of logwood dye. Thus the calcite is differentiated from other minerals. The reaction takes place in a few seconds. If left longer than one-half minute in the solution, the calcite will receive too thick a coating of $Al(OH)_3$ which is apt to peel off or crack on drying. Dolomite will react the same as calcite if immersed in the solution twenty minutes or more."

The low magnesian limestones are soft and easily broken in comparison with the highly dolomitic ones, so that a geologist can with practice rather closely approximate the magnesian content by the hardness and toughness of the stone when struck with the hammer. The dolomitic stones are also finer grained and more compact than the less magnesian ones of the same region.

When weathered surfaces are available the distinctions between high and low magnesia limestones can readily be made. The high magnesia limestones contain numerous straight cracks running in all directions, along which vein material has commonly been deposited in layers so extremely thin that the freshly broken surface scarcely indicates their existence. On being exposed to the weathering agents these cracks furnish access to dissolving fluids and the weathered surface of the rock looks as though some one had hacked the stone with a steel cutting implement. Where high and low magnesian limestones are interbedded, the contrast on weathered surfaces is striking.

The dolomitic limestones likewise have many more gash veins of quartz and calcite than do the purer limestones. There is also a greater amount of quartz in the vein fillings of the dolomites.

Where weathering has progressed downward to considerable depth the dolomites in various places of great crustal disturbances appear to be shattered as though by a blast of dynamite. One quarry near Lancaster in the highly dolomitic limestone region was, at one time, worked for road metal by means of a steam shovel without any blasting.

The highest grade limestones, composed almost entirely of calcium carbonate, can be located in certain regions by sink holes and caves due to their ready solubility or by heavy clay overburden. In such instances, outcrops are apt to be few.

All of these short cuts to the determination of the chemical compo-

sition of limestones by means of physical characteristics are useful, but must be used with care, as the most expert geologists in this line occasionally go astray, especially on entering a new region.

MINERALS OF UNMETAMORPHOSED LIMESTONES

Carbonates
- Calcite ($CaCO_3$)
- Aragonite ($CaCO_3$)
- Dolomite ($CaCO_3.MgCO_3$)
- Siderite ($FeCO_3$)
- Ankerite ($CaCO_3.(Mg,Fe,Mn)\ CO_3$)

Oxides
- Quartz (SiO_2)
- Chert, flint, basanite, chalcedony, etc. (all are composed of SiO_2)
- Hematite (Fe_2O_3)
- Limonite ($2Fe_2O_3.3H_2O$)
- Turgite ($2Fe_2O_3.H_2O$)
- Goethite ($Fe_2O_3.H_2O$)
- Pyrolusite (MnO_2)
- Rutile (TiO_2)
- Titanite ($CaO.TiO_2.SiO_2$)
- Zircon ($ZrSiO_4$)
- Cyanite ($Al_2O_3SiO_2$)

Sulphides
- Pyrite (FeS_2)
- Marcasite (FeS_2)
- Galena (PbS)
- Sphalerite (ZnS)
- Chalcopyrite ($CuFeS_2$)

Silicates
- Feldspars
  - Albite ($NaAlSi_3O_8$)
  - Microcline ($KAlSi_3O_8$)
- Micas, especially muscovite or sericite ($H_2KAl_3(SiO_4)_3$)
- Tourmaline (complex silicate of boron and aluminum with magnesium, iron or alkali metals)
- Garnet (andradite type) ($Ca_3Fe_2(SiO_4)_3$)
- Glauconite (ferric potassic silicate of variable composition)
- Staurolite ($HFeAl_5Si_2O_{13}$)
- Hornblende (complex silicate containing Al,Fe,Mn,Mg,Ca,Na and K)
- Hypersthene ($(Fe,Mg)SiO_3$)

Sulphates
- Gypsum ($CaSO_4.2H_2O$)
- Barite ($BaSO_4$)

Phosphates
- Phosphorite ($Ca_3(PO_4)_2$,$Ca_3(PO_4)_2F$, etc.)

Fluorides
- Fluorite (CaF_2)

Carbonaceous or bituminous matter
- Hydrocarbons

Of the minerals constituting the unmetamorphosed limestones, only a few are readily visible in most cases. The others are recognized only when they possess distinctive colors or when the carbonates are dissolved by acid and the residues are examined microscopically. The microscopic examination of residual insoluble materials has become in recent years a fertile field of research and has shown the presence of many minerals not previously suspected to exist in limestones.

The minerals present in unaltered limestones belong to three classes as to origin. These are (1) those minerals precipitated from solution either by organic agencies or by chemical inorganic precipitation; (2) those minerals that have been carried into the ocean by the land waters in suspension and have been dropped into the calcareous oozes; and (3) those minerals that have been introduced into the oozes or consolidated limestones in solution by infiltrating waters at some subsequent time. It is not easy to classify the minerals into these three groups for it is known that some of them occur in two or possibly all three divisions. Nevertheless it is well to recognize the different origins.

Of the minerals precipitated from solution calcite is the most important. Practically all the calcite has been carried into the ocean in solution and has there been precipitated by chemical reactions or

abstracted from the water by organisms and built into their structures which later collected in the ocean bottom. Most of the dolomite and silica, as well as the whole group of easily soluble minerals, were doubtless precipitated in a similar way. In regard to many others, even including the silicates, there is still considerable doubt as to whether they may not have been formed in some places by precipitation from solution contemporaneous with the formation of the calcareous ooze.

Of those carried into the ocean in suspension, we may include practically the entire list of limestone minerals, although it is probable that only small quantities of the more soluble ones were transported from the lands to the seas except in solution. The oxide and silicate minerals are mainly relatively insoluble so that most of them will be left on the surface in the decomposition of crystalline rocks in which they are most abundant, and are then apt to be picked up by surface streams, carried in suspension and eventually reach the sea. The indications are that limestones have been formed in places where only particles of small size derived from the lands could have been carried. This means that land-derived minerals can seldom be detected except by microscopic examination. Occasionally layers are found where the particles are large enough to be readily distinguishable with the naked eye. Most limestones in casual examination appear to be free from foreign minerals and yet even the purest are found to contain small particles when the residues are studied after the solution of the carbonates by acid. In those regions where deposition was near an area of igneous or metamorphosed rocks, the variety of minerals present is surprising. Most of them show evidences of rounding by attrition during transportation or pitting by corrosive action. Although the residues of few of the Pennsylvania limestones have been investigated, enough has been determined to show that they contain small fragments of a rather large number of the minerals given in the above list.

Many of the minerals present in limestones are of secondary origin, having been introduced by water circulating through the pores and larger cavities at a period following deposition of the oozes and continuing even after consolidation of the original sediments. It is generally believed that these new minerals are introduced by water considerably above the temperature of shallow meteoric or surface waters, such as would be found in deep seated waters, although there is some evidence to support the belief that this process at times takes place at shallow depths. When the calcareous sediments have been buried beneath hundreds or thousands of feet of later deposits there is no doubt but that the circulating waters, regardless of their original source, are higher in temperature and have a decidedly higher mineral content and hence do more work of introducing new minerals. Further, such waters do much work of concentration of the ingredients finely distributed throughout the original oozes. At one time it was believed that most of the silicates, among them the feldspars, could be formed only at high temperatures, but there are a number of cases tending to show that feldspars have formed in limestones that have never been subjected to high temperatures such as are necessary for the formation of most of the metamorphic minerals.*

In the limestones of Pennsylvania, the most prominent example of

*Singewald, J. T., Jr., and Milton, C., Authigenic feldspar in limestone at Glens Falls, New York: Bull. Geol. Soc. Amer., vol. 40, pp. 463-468, 1929.

secondary introduction or concentration of mineral matter is that of the flint nodules and lenses that are so abundant in certain of the Paleozoic limestones. Some of the silica undoubtedly came from the limestones themselves but in other cases siliceous waters entered the limestone strata from near-by more siliceous rocks. Part of the flint is of the black variety (basanite) but in places it is lighter in color and passes into the white chalcedony type. Some of the masses are of large size, several feet in diameter, but more frequently one observes nodules or lenses only a few inches thick. When the silica was brought in, it in part filled previously existing cavities, but generally it replaced the carbonates. It is not unusual to find fossils in which the original calcareous shells or casts have been entirely replaced by black flint. Pyrite has also been concentrated in the limestones in a similar manner.

MINERALS OF METAMORPHOSED LIMESTONES

Carbonates
- Calcite ($CaCO_3$)
- Dolomite ($CaCO_3.MgCO_3$)
- Ankerite ($CaCO_3.(Mg,Fe,Mn)\ CO_3$)

Oxides and Hydroxides
- Quartz (SiO_2)
- Hematite (Fe_2O_3)
- Magnetite (Fe_3O_4)
- Pyrolusite (MnO_2)
- Rutile (TiO_2)
- Titanite ($CaO.TiO_2.SiO_2$)
- Perovskite ($CaTiO_3$)
- Dysanalyte (titano-niobate of Ca and Fe)
- Corundum (Al_2O_3)
- Ruby (Al_2O_3)
- Emery (corundum and magnetite or hematite)
- Spinel ($MgO.Al_2O_3$)
- Periclase (MgO)
- Brucite ($Mg(OH)_2$)

Sulphides
- Pyrite (FeS_2)
- Pyrrhotite ($Fe_{11}S_{12}$)
- Chalcopyrite ($CuFeS_2$)
- Chalcocite (Cu_2S)
- Tetrahedrite ($Cu_8Sb_2S_7$)
- Realgar (AsS)
- Arsenopyrite ($FeAsS$)
- Galena (PbS)
- Sphalerite (ZnS)
- Molybdenite (MoS_2)

Sulphates
- Gypsum ($CaSO_42H_2O$)

Phosphates and fluorides
- Apatite ($(CaF)Ca_4(PO)_4)_3$ or $CaCl\ Ca_4(PO_4)_3$)
- Fluorite (CaF_2)

Elements
- Sulphur (S)
- Graphite (C)

Silicates
- Micas
  - Phlogopite ($((H,K(Mg,F))_3Mg_3Al(SiO_4)_3$)
  - Muscovite (sericite) ($H_2KAl_3(SiO_4)_3$)
  - Biotite ($((H,K)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$)
- Feldspars
  - Orthoclase ($KAlSi_3O_8$)
  - Albite ($NaAlSi_3O_8$)
  - Anorthite ($CaAl_2Si_2O_8$)
- Pyroxenes
  - Enstatite ($MgSiO_3$)
  - Hypersthene ($(Fe,Mg)SiO_3$)
  - Diopside $CaMg(SiO_3)_2$
  - Diallage (similar to diopside with Al)
  - Augite ($CaMg(SiO_3)_2$ with $(Mg,Fe)(Al,Fe)_2SiO_6$)
  - Wollastonite ($CaSiO_3$)
- Amphiboles
  - Tremolite ($CaMg_3(SiO_3)_4$)
  - Actinolite ($Ca(Mg,Fe)_3(SiO_3)_4$)
  - Hornblende (complex silicate containing Al,Fe,Mn,Mg,Ca,Na and K)
- Garnet (grossularite) ($Ca_3Al_2(SiO_4)_3$
- Epidote ($Ca_2(Al,Fe)_2(AlOH)(SiO_4)_3$)
- Zoisite $Ca_2(AlOH)Al_2(SiO_4)_3$
- Olivine ($(Mg,Fe)_2SiO_4$)
- Tourmaline (complex silicates of boron and aluminum with magnesium, iron or the alkali metals.)
- Talc ($H_2Mg_3Si_4O_{12}$)
- Serpentine ($H_4Mg_3Si_2O_9$)
- Vesuvianite ($Ca_6\ [Al(OH,F)]\ Al_2(SiO_4)_5$)
- Gehlenite ($Ca_3Al_2Si_2O_{10}$)
- Scapolites (silicates of Al, Ca, and Na)
- Forsterite (Mg_2SiO_4)
- Monticellite ($CaMgSiO_4$)
- Chondrodite (fluo-silicate of magnesium)
- Humite (similar to chondrodite)

In many places throughout Pennsylvania and elsewhere, the limestones have been subjected to such intense compression by mountain building forces that the temperatures of the rocks and the circulating waters were sufficiently high to cause important mineral changes. In other cases the limestones have been intruded by molten igneous matter which has caused similar heating and new combinations. The minerals formed under either of these conditions are known as metamorphic minerals and constitute a large group.

In the metamorphism of calcareous rocks the greatest change is that of re-crystallization by which marbles are formed from the original limestones. This process is more fully discussed on a later page.

The oldest limestones of the State have been subjected to great earth pressures at several different periods and contain many metamorphic minerals; whereas the youngest limestones have been little disturbed and have few metamorphic minerals. Even in rocks of the same age, some are found in regions of former great disturbances and consequent heating, whereas in other sections such forces have never been exerted on the rocks. The most intense compression, as shown by the complicated rock folds, has taken place in the southeastern part of Pennsylvania. There was less compression in the central region and much less in the western portion. The pre-Cambrian limestones of southeastern Pennsylvania as a result of greater age and more compression contain many of the minerals listed above, the Cambrian and Ordovician limestones of the southeastern and central portions of the State have suffered less compression and have few new minerals, and the Carboniferous limestones of the western section are practically devoid of metamorphic minerals.

A few examples will illustrate these changes. Carbonaceous matter occurring in the Carboniferous limestones of western Pennsylvania consists of amorphous black hydrocarbons whereas in the pre-Cambrian limestones of Bucks, Chester, and Northampton counties flakes of crystalline graphite are found. Graphite in thin flakes is abundant in the pre-Cambrian metamorphosed limestones of the State but unlike somewhat similar Canadian occurrences has never been utilized. Instead the graphite production of Pennsylvania has all been derived from graphite schists or gneisses which are so intimately associated with these limestones in several places that they are regarded as a single formation.

Tremolite is found in the marbles of the eastern part of the State, but not in the western part, although the ingredients necessary are present as dolomite and quartz. The original muddy (argillaceous) materials of the unmetamorphosed limestones appear as sericite (muscovite) mica in fairly coarse flakes in the metamorphic limestones of Chester and Lancaster counties.

CHAPTER II

PHYSICAL PROPERTIES OF LIMESTONES

Limestones not only vary in chemical and mineralogical composition but also in their physical properties. The variations in chemical composition may, and generally do, result in different physical characteristics but the converse is not equally true. Some of the physical features of rocks that are of scientific interest and in most cases of economic value are color, odor, texture, structure, hardness, toughness, specific gravity, porosity and absorption, and strength.

COLOR

A pure limestone or dolomite should be perfectly white or nearly so, but actually very few are, as impurities of some sort are almost always present and many of these affect the color. Pure crystals of calcite and dolomite may be transparent to translucent, but these colorless varieties are never seen as the ordinary constituents of limestones. Some of the purest dolomites found in Pennsylvania, containing little more than 1 per cent of impurities, have a noticeable pale buff color. The color and the texture combined suggest, on the fractured surface, light-colored cheese. This color seems to be inherent in the dolomite itself.

The color is almost entirely a result of the chemical constitution of the stone although the physical characteristics such as variations in porosity, size of grain, and degree of crystallinity may have some effect. The iron oxides, hematite, turgite, limonite, and goethite, produce the various shades of buff, yellow, pink, and even red, and carbonaceous matter is responsible for the blue, gray, and even black colors. The iron oxide colors are permanent but those due to carbonaceous materials will slowly disappear by oxidation if exposed to the action of the atmosphere. It is a very common observation that limestones become whiter on exposure and the beds at their outcrop are in most cases whiter than they are beneath the cover of soil and other strata.

Changes of color of this kind are not objectionable and do not unfit a stone for structural purposes. But limestone containing pyrite (or perhaps marcasite) is apt to weather in unsightly blotches due to the formation of limonite. Discoloration is further discussed in the chapter on weathering.

When both iron compounds and carbonaceous matter are present in a limestone, the iron is apt to exist as light-colored or colorless ferrous compounds. If by oxidation the carbonaceous substances are removed the iron passes into the ferric condition and the stone becomes buff, yellow, or reddish, depending upon the particular compound formed and the amount present. These changes are most noticeable in very dark limestone.

In most limestones the color is fairly uniform throughout the individual beds, but varies from bed to bed. In those of a conglomeratic character, however, many beds present a blotched appearance due in part to different kinds of fragments but more to the distinctions between the fragments and the matrix. In almost every instance the

contrast is greatest on the weathered surfaces. Some of the Beekmantown limestones of the State show little differences of color in the freshly broken rock, but are prominently mottled on the weathered surfaces. The distinctions in the beds of limestone of different composition are also accentuated on exposure to the weather. This is especially noticeable where the separate beds contain different amounts of magnesia. In the Conococheague (Allentown) limestone this is almost a diagnostic characteristic. The formation is composed of alternating beds of low and high magnesian limestones which show slight differences in color in a freshly worked quarry but marked banding on long exposed surfaces. Those strata containing high percentages of magnesia, that is more dolomitic, become much whiter than those of low magnesia content.

The most highly colored limestones of Pennsylvania are the Triassic limestone breccias which are found in Adams, Berks, Lancaster, and York counties and are described under those counties. Their colors are due to a variety of white to vari-colored fragments in a red calcareous matrix.

In general, marbles everywhere show greater color contrasts than the unmetamorphosed limestone. There is a tendency for the colors to become concentrated during the process of crystallization (marmorization). Thus an original limestone with carbonaceous matter fairly evenly distributed may show beautiful wavy lines or narrow bands of dark matter in a white to gray matrix when changed to marble. New minerals of higher color than the original ones may develop. Talc and serpentine are rather common in the marble and produce pleasing light green markings.

The compressive forces producing marbles are apt to break the limestone into angular fragments and the infiltrating materials that later fill the cavities, if of different color, produce beautiful effects. This class of brecciated marble has long been used extensively in interior decoration. Those most used in this country are almost entirely of foreign origin, coming mainly from Italy.

ODOR

In general, limestones are odorless but there are a few exceptions. Argillaceous limestones may give a faint, clayey odor after being slightly moistened by the breath. The most noticeable, however, are those called fetid limestones, or "stink stones". These, when freshly broken give a perceptible odor of hydrogen sulphide (H_2S). It is not uncommon to find one or more layers in certain quarries in which the odor is so noticeable that the quarrymen are familiar with the phenomenon and can designate the particular beds where it is strongest. The odor is attributed to the presence of H_2S contained in the pores of the rocks and probably derived from the decomposition of some organic matter formerly present. It has been noted in rocks of different colors from white to dark.

TEXTURE

Texture as applied to rocks has been defined as "the appearance, megascopic or microscopic, seen on a smooth surface of a homogeneous rock or mineral aggregate due to the degree of crystallization (crystal-

linity), the size of the crystals (granularity), and the shapes and interrelations of the crystals or other constituents (fabric)."* As applied to limestones, which in the original condition are rarely crystalline, it has reference to the size and shape of the individual particles and the amount of cementing material. In the crystalline varieties (marbles) it refers to the size of the individual crystals.

We have fine-grained compact limestones in which the naked eye cannot detect any individual particles and the rock breaks under the hammer with a conchoidal fracture almost as perfect as in glass. This type is represented in a number of the fresh water Carboniferous limestones in the western part of the State. In other cases the particles are coarser and on a weathered surface appear much like roughened grains of sand. The cementing material may be deficient and the rock so porous that it gives forth a hollow sound when struck. The stone may be a mass of angular fragments of fossil shells either feebly or firmly cemented together by calcium carbonate. Excellent examples of this type are found in the Ames and Greenbrier limestones.

As originally deposited limestone may be either amorphous or crystalline, but in the older limestones of the State we now find all the materials in the crystalline condition owing to the great amount of compression and heating that they have experienced by the mountain-building forces that were so active during the pre-Cambrian and at the close of the Ordovician and Permian periods. If the crystalline grains are small and not particularly noticeable we commonly retain the name limestone, but if coarser the rock is called marble.

Some of the Cambrian and Ordovician marbles in Pennsylvania, especially in the Chester, Lancaster, and York valleys have crystals up to one-twentieth of an inch in diameter, perhaps even larger. In the pre-Cambrian marbles, the crystals may be as much as one-half inch. In New Jersey some of the Franklin limestones in places have individual crystals over two inches in diameter.

In general, the more crystalline limestones possess the property of taking a high polish, which is not the case with the finely crystalline or amorphous limestones. Most of the Cambrian and Ordovician and even many of the younger limestones take a good polish. This even applies to the Triassic limestone breccias of the State.

Several types of limestones are differentiated by characteristic kinds of textures. These are conglomerates and breccias of several varieties, oolites, and pisolites.

Normal conglomerates. A conglomerate consists of rounded pebbles or even boulders cemented to form a firm rock. In general, conglomerates are rare among the limestones yet they are not entirely absent. In the weathering of limestones, solution is the most active process, and the materials are transported in solution. Occasionally, however, fragments of limestones resulting from the disintegration of some previous bed may be carried into a stream and transported in suspension or rolled along the bottom. Abrasion tends quickly to wear the angular fragments to rounded pebbles or if carried far to reduce them to fine sand or powder. If they come to rest before reaching the final stage, they form a permanent pebble or gravel bed, just as happens so frequently with fragments of the more resistant rocks such as

*Holmes, Arthur, The nomenclature of petrology; second edition, 284 pp. London, 1928.

sandstones, quartzites, and igneous rocks. If these limestone pebbles are later consolidated by infiltration and precipitation of some cementing materials, limestone conglomerates result.

Within the Triassic deposits of Pennsylvania, there are some limestone conglomerates of limited extent. In places the pebbles are so angular that they are more properly termed breccias.

Intraformational conglomerates. Walcott* states that "an intraformational conglomerate is one formed within a geologic formation of material derived from and deposited within that formation." The individual pebbles have come from unconsolidated or feebly consolidated strata of little greater age than the bed of conglomerate. Waves are believed to have broken up some of the recently deposited beds and to have rolled the fragments into the place where the conglomerates are now found. Since the pebbles were formed of calcareous mud rather than hard stone they would wear rapidly by abrasion so it seems probable that they were carried only short distances. After coming to rest the larger interstices were filled with calcareous oozes and the finer by calcareous cementing material by precipitation to consolidate the mass. Intraformational conglomerates are also attributed in origin to submarine slipping or slumping and consequent breaking of the thin layers of partly indurated ooze, also to the action of the sun drying the exposed sediments at low tide and causing the thin surface layers to break loose and curl up to be later transported and piled up by wind and wave action, and to several other causes. Fragmentation by wave action appeals to the writer as the most important cause.

The Cambrian and Ordovician limestones of eastern Pennsylvania contain many intraformational conglomerates which indicate that the seas where these limestones formed were so shallow that storm waves frequently broke up many of the newly formed beds of calcareous mud. In some cases the individual fragments are a few feet in diameter although generally they are only a few inches or less in size. In some cases the matrix is so closely similar to the fragments that one has difficulty in detecting their conglomeratic character in the unweathered rocks. Minute differences become accentuated on weathering so that the true character becomes noticeable on weathered surfaces. In some places, especially in the Beekmantown limestone, the fragments may be fairly high in magnesia whereas the matrix may contain very little or vice versa. In such cases, the weathered surfaces present a decidedly mottled appearance.

Edgewise conglomerate. At times when the beds of partially consolidated calcareous mud were broken up, thin fragments were carried by the waves and finally dropped with their edges upright or at an angle to the bedding plane. Consolidated in this position, they become edgewise conglomerates. Rocks of this kind are prominent features of the Cambrian and Ordovician limestones of the eastern part of the State.

Normal breccias and intraformational breccias. When the fragments of clastic rocks have not been abraded to the rounded forms but preserve their angular shape, the rocks are called breccias. Generally

*Walcott, Charles D., Paleozoic intraformational conglomerates: Bull. Geol. Soc. America, vol. 5, pp. 191-198, 1894.

it indicates transportation over short distances, especially so in the case of the limestones which, because of their soft character, are easily rounded by abrasion. Except for the shape of pebbles, the normal and intraformational breccias are like the similar varieties of conglomerates. In places it is not possible to separate breccias and conglomerates as they naturally grade into each other and within the same bed some of the fragments may be decidedly angular and the others well rounded. The occurrence of limestone breccias within the State is the same as that of the limestone conglomerates.

Oolites and pisolites. Very commonly in the limestones of Pennsylvania, especially those of the Cambrian and Ordovician, one notes beds of spherical grains that are composed of concentric layers. If these pellets are of small size they are termed oolites because of their resemblance to fish roe, whereas if they are the size of small peas they are called pisolites. The small varieties, ranging in size from bird shot to buck shot, are much more common, although some have been observed in the Conococheague (Allentown) limestone that are almost as large as small peas. In some cases the particular bed consists almost entirely of these oolitic spherules bound together by calcareous cement but in other cases the oolites are sparingly distributed throughout the individual strata. They are occasionally noted as small lenses or pockets within the bed. On weathering, the oolites in some cases dissolve more readily than the cementing material, leaving a surface with semi-spherical pittings, but in other instances the oolites are more resistant and the spherules project above the matrix.

Along Monocacy Creek just north of Bethlehem an unusual type of oolite has been found in the Conococheague (Allentown) limestone, in which the lower portion, usually a little less than one half, of each spherule is dark and contains considerable carbonaceous matter, quartz, kaolin, limonite, and pyrite and the upper portion is entirely white dolomite. An investigation* indicates that the original oolites, probably composed mainly of aragonite, were largely dissolved by permeating waters, leaving the less soluble material as loose particles in the bottoms of the cavities. At some later time other percolating waters precipitated pure dolomite to fill the upper portions and to cement the residues of the former oolites into reconstituted spherules as they occur today.

There is an extensive literature on the origin of oolites, but it does not seem advisable to discuss here the various explanations offered for their formation. They are plainly of the nature of concretions and formed in most cases in shallow marine waters.

STRUCTURE

In the discussion of structure, it is well to recognize two divisions which may be described as minor and major. The first apply to features of the individual beds and the latter to series of beds. The following grouping is not entirely satisfactory in several respects but serves the purpose of systematizing the descriptions of features of limestones.

*Wherry, Edgar T., A peculiar oolite from Bethlehem, Pennsylvania: Proc. U. S. Nat. Mus., vol. 49, pp. 153-156, Washington, 1915.

Classification of limestone structures

Minor structures	Major structures
Banding	Stratification
Cross-bedding	Unconformities
Stylolites	Joints
Surface features	Folds
Ripple marks	Faults
Mud cracks (sun cracks)	
Rain drop pits	
Animal tracks, trails and burrows	

MINOR STRUCTURES

Banding. Within individual beds of limestone thin parallel bands are occasionally observed. These may owe their origin either to differences in the size, shape, or composition of the constituents or to the coloring. If due to color they may be either original or secondary.

Cross-bedding. In the deposition of limestones almost all stratification lines are parallel to the bedding planes, but in some cases the stratification lines within the individual beds may be at decided angles to the surfaces or the bedding planes. This type of structure is called cross-bedding. It is common in sandstones, especially noticeable in the Loyalhanna sandy limestone of the southwestern part of the State, but occasionally noted as a prominent feature of some of the fairly pure limestones and dolomites of the Cambrian and Ordovician periods in the central and eastern counties. It is developed where some of the materials transported in suspension by shifting currents in shallow water have been dropped on sloping surfaces.

Stylolites. Stockdale* describes stylolites as follows:

"Stylolites consist of a series of alternating, interpenetrating columns of stone which form an irregular, interlocked parting or suture in rock strata. In their most common occurrence they are found along the bedding or lamination planes of limestone, resulting in an intricate interteething of the rock by the alternating downward and upward projection of the columns of one layer into the opposite. The length of these columns varies from a small fraction of an inch to a foot or more. The width is as variable as the length. Oftentimes the union of the stone at a stylolite-parting is so firm that the rock will split more readily elsewhere than along this jagged suture. Where this parting is cut across, as in the wall of a quarry, it presents a rough, jagged line. To such a line the terms "stylolite-seam" or "stylolite-line" may well be given. Because of the intricate interlocking of the columns, these lines have been compared by Vanuxem to the sutures of the human skull. Where the stone has been split along a stylolite-parting, an extremely irregular, pinnacled surface is presented. The term "stylolite-surface" might well be applied to such. The term "stylolite" (from the Greek word meaning "column") applies to each individual, penetrating column. Thus it is seen that a stylolite-seam is made up of many stylolites whose direction of penetration, with few exceptions, is at right angles to it.

*Stockdale, P. B., Stylolites, their nature and origin: Indiana Univ. Studies, vol. IX, Study No. 55, 89 pp., Bloomington, 1922.

"Stylolites are always characterized by two principal features:

1. An ever-present clay cap which comes to rest at the end.
2. Parallel fluting, or striations, on the sides."

Many different explanations have been offered for the origin of stylolites, no one of which has received general acceptance. Nevertheless there seems to be a growing appreciation of the theory of differential solution along bedding planes, joints, faults, or other cracks as the most important cause. Stockdale in the article mentioned discusses the various theories.

The Pennsylvania limestones contain many examples of stylolitic structure but seldom are they pronounced or even observed except when examined in detail. They are almost everywhere small. Although in most cases developed along bedding planes, one occurrence was noted where the stylolites were developed along a minor fault.

Ripple marks. Many of the limestones of Pennsylvania show beautiful ripple marks where wave action in shallow water threw the original unconsolidated calcareous ooze into ridges and troughs. These have been well preserved and show considerable variation in wave length and height. Their rather common occurrence furnishes additional evidence for the shallow water deposition of most of the limestones of the State.

Mud (Sun) cracks. During the formation of the limestones occasional unusually low tides seem to have left some of the loose unconsolidated calcareous muds exposed to the drying action of the sun sufficiently long for mud cracks to form. These have been preserved in many of the Paleozoic limestones of the State. Some of the cracks are nearly an inch deep. In a quarry of the Helderberg limestone near Blain a layer of limestone a few inches thick readily breaks into polygonal blocks due to these old mud cracks. There is a marked tendency to regularity of size in the individual mud-cracked limestone beds due mainly to the uniformity in composition of the deposits of ooze.

Rain-drop pits. Occasionally one finds small pits on the surface of limestone formed by a few heavy rain drops striking some of the unconsolidated deposits when exposed at low tide.

Animal trails and burrows. Various animals possessing the power of locomotion by crawling over the deposits of calcareous mud left trails and others burrowed within the deposits. Some of the surface markings on the limestones of the region seem to have been produced in this way.

MAJOR STRUCTURES

Stratification. Limestones almost everywhere are composed of layers, beds, or strata. Stratification, which expresses this characteristic, is regarded as one of the major group of rock structures found in limestones. The stratification is much more regular in limestones than in some of the coarser sedimentary rocks and yet there are great variations. Cessation of deposition for a time marks the separation of the different beds. In some regions these periods of deposition and cessa-

tion seem to have been regular or rhythmic and the beds are fairly uniform in composition and thickness, but such conditions are uncommon in the limestones of Pennsylvania. Instead, thick and thin beds of varying composition generally alternate without any order of regularity. It is also rare to find in the folded and faulted areas of the State any one bed or series of beds sufficiently unique or widely distributed to aid in correlation and thus in determining the thickness of the various formations. For this reason we are still considerably in doubt concerning thicknesses of many of the limestone formations described on later pages.

The argillaceous limestones are generally thin-bedded, the individual strata seldom more than an inch thick; the better grade limestones occur in beds from a few inches to several feet but seldom more than 5 feet thick, whereas the arenaceous limestones, such as the Loyalhanna of southwestern Pennsylvania, may have beds as much as 20 feet thick.

In general the pre-Cambrian limestones of the State as well as some of the early Paleozoic strata have been so greatly metamorphosed that all stratification lines have been obliterated.

Unconformities. An unconformity has been defined by Twenhofel* as "a surface of erosion or non-deposition separating two groups of strata." In other words the rocks above and below the unconformity have been deposited at different times under different conditions with the unconformity between them representing a period of non-deposition and erosion. There are two main types of unconformity. The beds below may have been tilted before the deposition of the overlying beds so that the two series are not parallel, in which case the unconformity is called a nonconformity. If the beds above and below the unconformable contact are parallel, it is called a disconformity.

If the unconformity is local, such as may happen when a current erodes a bed in one place by excavating a channel in the recently deposited sediments without interrupting the fairly continuous deposition in other near by places, it is called contemporaneous erosion or unconformity. All kinds of unconformities are to be found in the Pennsylvania limestones and one needs to be on his guard for them in any investigations. The failure to find an expected series of rocks in any one place may be due to their non-deposition or to their deposition and subsequent removal by erosion before the overlying beds were laid down. The correct interpretation of such a problem may have considerable economic significance.

Joints. All kinds of sedimentary rocks are broken into blocks by cracks that are roughly perpendicular to the bedding surfaces. These are called joints. They are caused by shrinkage of the sediments or by later compression or tension due to earth movements. Where the joints are regular, not too close together, and occur in different directions such that rectagular blocks of convenient size can be quarried they are of great advantage and materially reduce quarry and dressing costs. The joints are normally in more or less parallel series and commonly two series approximately at right angles to each other break the rocks into rectangular blocks. In many parts of the State such

*Twenhofel, W. H., Treatise on Sedimentation, 661 pp. Baltimore, 1926.

conditions prevail. In other places, however, the great mountain-forming movements that affected the region at different times have resulted in so many joints cutting each other at different angles and so close together that it is not practicable to quarry the limestones for building purposes. In a quarry formerly worked a few miles northwest of Lancaster the dolomitic limestones were broken in the different beds into angular pieces only a few inches in diameter. For a time the quarry was worked by steam shovel without any previous drilling or blasting. In general the limestones occurring in the greatly folded areas do not present favorable conditions for quarrying building stone and yet there are places where blocks of desirable shape and size are found. Stone buildings throughout practically every limestone district present evidence of this.

Folds. To those persons living in regions where the strata are horizontal or nearly so, it may be difficult to appreciate the complicated folds into which many of the limestone strata of the eastern and central portions of the State have been thrown. From folds of microscopic size to those several miles in width, from folds involving only a few inches or less of strata to those affecting thousands of feet of material, from open low folds to steep tightly compressed ones, from upright folds to overturned almost flat or recumbent ones, the limestones of the State offer excellent examples. That both thick and thin beds could be thrown into such complicated structures without more breaking or displacement by faulting keenly impresses one with the tremendous forces exerted and the amount of overburden of other strata that permitted such deformation without more fracturing than is observable. The recognition of the character of folding is of major importance in many sections where large quarry operations are located. The failure to do the necessary geologic work to determine the structure has been the cause of much useless expenditure of money and effort in a number of places. Many examples of folded strata are given in quarry descriptions in later chapters of this volume.

In central and eastern Pennsylvania the folds make it difficult to work any particular bed far from the outcrop because the normal steep dips carry the beds to depths that cannot be profitably worked. On the other hand in the western part of the State certain beds of limestone are nearly horizontal and their outcrops can readily be followed into the hillside. The more persistent limestone beds of this region form excellent horizon markers.

Faults. Yielding of the limestone strata under extreme compression took place by folding or by faulting. The latter term expresses the process of breaking and displacement of one portion of the strata with reference to the others. The surface along which movement has taken place is called a fault plane or surface. The limestones of the State present excellent illustrations of faults in which the slip of the displaced beds varies from a fraction of an inch to those in which the movement is measured by several thousand feet. The movement may be upward, downward, horizontal or more frequently may involve both vertical and horizontal displacement. The rocks on both sides of the fault plane generally show smooth polished or striated surfaces termed slickensides. Normal faults in which the overlying portion (hanging wall) has gone down are most common in this sec-

tion, although there are examples of the other kinds of faults, reverse or thrust, in which the overhanging rocks have been thrust upward and forward considerable distances. There are many faulted areas where as yet we do not have sufficient data to determine the kind of faulting or the amount of the displacement that has taken place. In quarry areas it is highly important to obtain all the information possible concerning any faults known or suspected to be present in advance of quarry developments for by so doing many difficulties may be worked out economically. The writer has seen cases where the failure to solve the fault problems of the region has resulted in considerable loss. In descriptions of quarries on later pages many examples of faults are given.

HARDNESS

The hardness of a rock depends upon the hardness of the individual mineral particles composing it and upon the amount and character of the cementing material. Limestone is composed primarily of calcite with a hardness of 3 in Moh's scale, in which minerals are classified on a scale of 1 to 10. Dolomite is slightly harder, ranging from 3.5 to 4. Both are scratched readily by a knife or a piece of glass but cannot be scratched with the fingernail.

The cementing material for practically all our limestones is either calcium or calcium-magnesium carbonate with the hardness of calcite or dolomite. The amount varies from almost zero, in which the pore spaces are so numerous that the rock can be crumbled in the hand, to compact rock with almost no pore space. Most of the limestones of Pennsylvania are firmly cemented.

Hardness is important in rocks used for road building purposes. A recent publication of the U. S. Department of Agriculture* furnishes the following information concerning the testing of hardness.

"Hardness is the resistance which the rock offers to the displacement of its surface particles by abrasion. * * * The hardness of a rock is determined by both the Dorry hardness test and the Deval abrasion test. The abrasion test is also a measure of the toughness of rock and supplements in this respect the impact test for toughness.

Dorry hardness test.—"Hardness is determined by drilling a cylindrical rock core 25 millimeters in diameter, from the specimen under examination and subjecting it to the abrasive action of quartz sand fed upon a revolving steel disk. The end of the specimen is worn away in inverse ratio to its hardness, and the amount of loss is expressed in the form of a coefficient as follows:

$$\text{Coefficient of hardness} = 20 - \frac{W}{3}$$

where W is the loss in weight after 1,000 revolutions of the disk."†

Deval abrasion test.—"This test is a measure of the combined action of abrasion and impact and is considered the most important test

*Woolf, D. O., The results of physical tests on road-building rock: U. S. Dept. Agr., Miscl. Pub. No. 76, 148 pp., Washington, 1930.

† "On account of the lack of steel-tired traffic, this test is now considered to be of little importance. It has largely been replaced by the Deval abrasion test, the results of which are influenced by the hardness of the material under test. The hardness test is still made, however, because the information obtained from the three tests, hardness, toughness, and abrasion, furnishes a more complete knowledge of the material than would be obtained if this test were omitted."

for road-building rock. The test sample consists of approximately 50 pieces as nearly cubical as possible, weighing 5,000 grams, and broken by hand in the laboratory from a large piece of rock. The sample is tested in a large cylinder which is mounted at an angle of 30° with the axis of rotation of the testing machine. The rock fragments forming the charge are thus thrown from end to end of the cylinder twice during each revolution and strike and rub against each other and the sides of the cylinder. After 10,000 revolutions the charge is screened over a No. 12 sieve and the amount passing is expressed as a percentage of the initial weight and is called the per cent of wear. The French coefficient of wear is calculated as follows:

$$\text{French coefficient of wear} = \frac{40}{\text{Per cent of wear}}\text{''}$$

The average hardness of limestones according to these tests is about 14.1, dolomite 14.9, and marbles 13.1.

The hardness of certain Pennsylvania limestones and dolomites taken from the same report is given at the close of this chapter.

TOUGHNESS

Toughness has been defined as the resistance which a stone "offers to fracture under impact." The Deval abrasion test for hardness described above is valuable for determining toughness, but in addition the U. S. Bureau of Public Roads in the same report furnishes the following description of a toughness test.

"Toughness is determined by subjecting a cylindrical test specimen 25 millimeters high and 24 millimeters in diameter to the impact produced by the fall of a 2-kilogram hammer upon a steel plunger whose lower end is spherical and rests on the test specimen. The energy of the blow is increased by increasing the height of fall of the hammer 1 centimeter after each blow. The height of fall in centimeters at failure of the specimen is called the toughness."

The average toughness of limestone and dolomite is about 9 and of marble about 6.

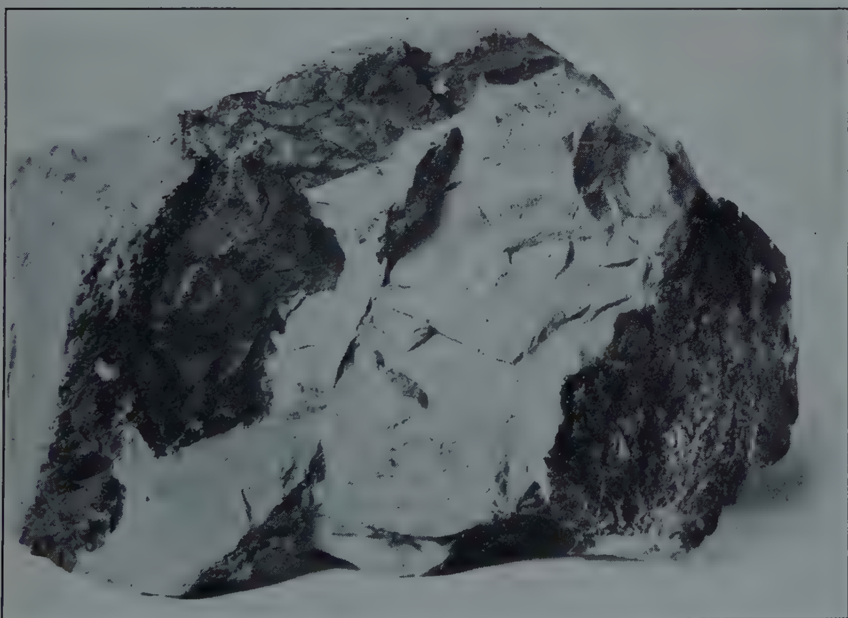
The table at close of chapter gives data on toughness tests of Pennsylvania limestones and dolomites.

SPECIFIC GRAVITY AND WEIGHT PER CUBIC FOOT

Limestones, dolomites, and marbles vary considerably in their specific gravity. In Technologic Paper No. 349 of the U. S. Bureau of Standards, the methods of determining the apparent and true specific gravities of limestones are described as follows:

"Apparent specific gravity is the ratio of the dry weight of a material to the weight of an equal volume of water. The only difficulty involved in this determination is that of obtaining accurately the volume of the specimen. The simplest way of doing this is to weigh the specimen dry and then weigh it suspended in water. The difference between the two weights in grams is equal to the volume of the specimen in cubic centimeters. However, in making this test on porous materials like most limestones one has to prevent the specimen from absorbing while weighing it suspended

A. Thin black lenses are developed parallel to bedding or nearly so. West Bethlehem, Lehigh County.

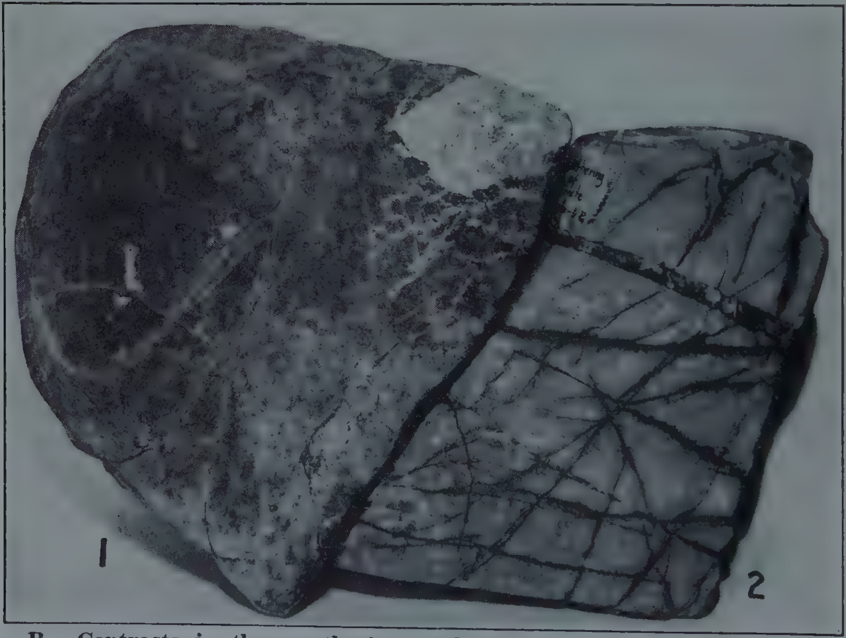


B. Less regular segregations in Beekmantown limestone, Friedensville, Lehigh County.

Black flint segregations in dolomitic limestones.

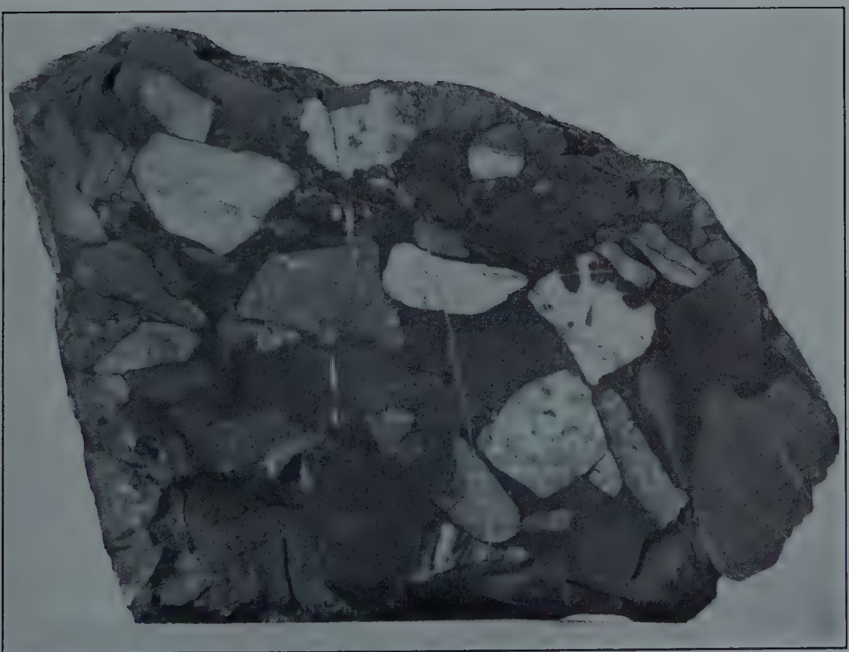
A. Beekmantown limestone, Topton Furnace quarry, 2-½ miles northwest of Topton, Berks County. A layer of dolomite between two low magnesian limestone beds is filled with gash veins.

	Above dolomite bed	Dolomite bed	Below dolomite bed
SiO_2	5.68	6.54	6.54
$Al_2O_3+Fe_2O_3$	1.36	3.24	1.52
$CaCO_3$	93.97	57.76	84.01
$MgCO_3$	.86	35.74	7.96

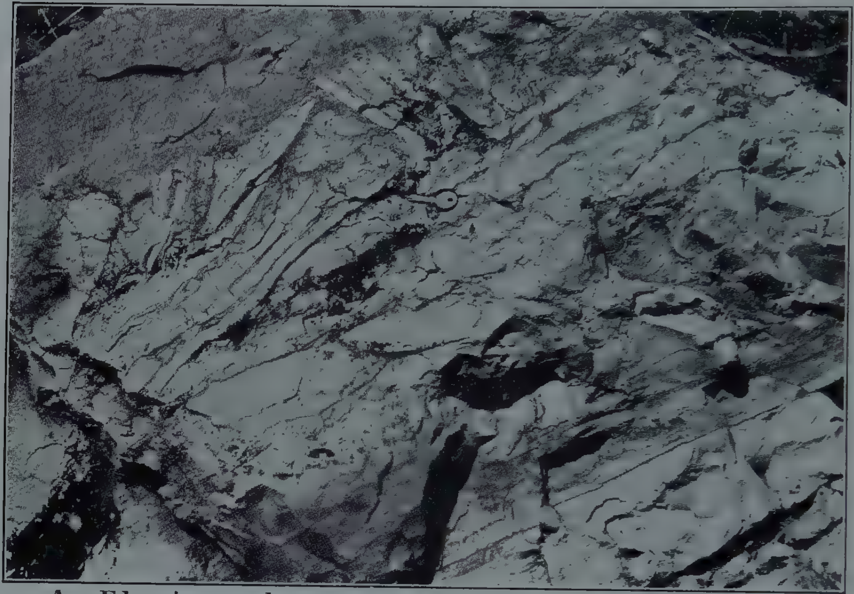


B. Contrasts in the weathering of high and low magnesian limestones. Florin, Lancaster County.

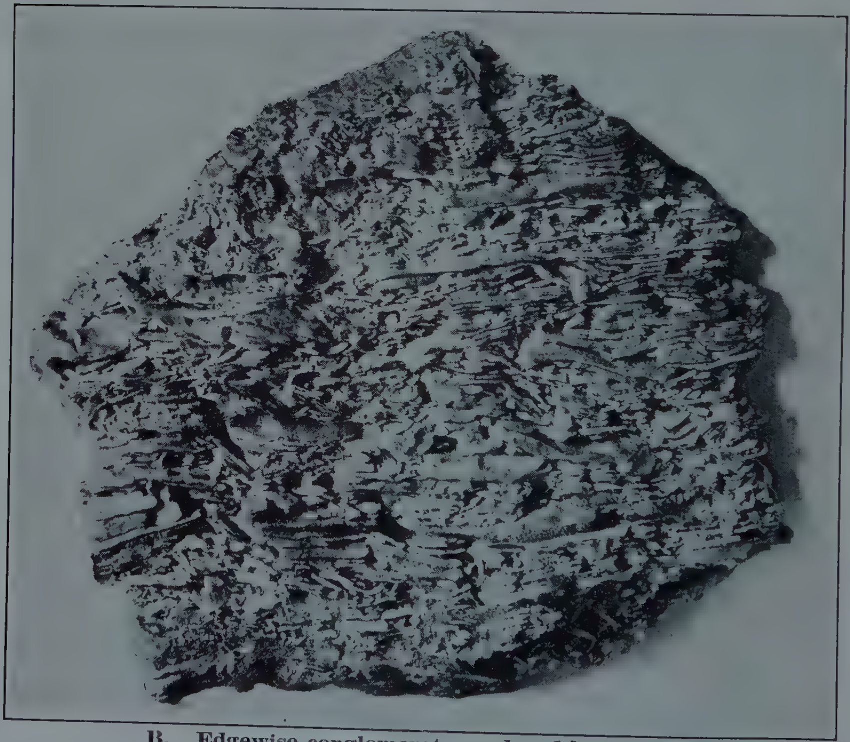
A. Massive bed of Triassic "Potomac marble," New Market, York County.



B. Polished block of Triassic "Potomac marble," one mile southeast of Reading, Berks County. Fragments are white, gray, mottled, pink and red in red matrix.



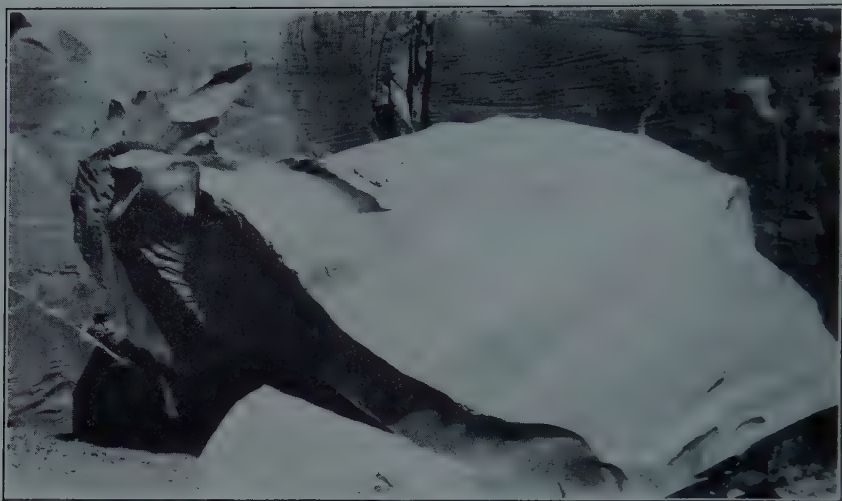
A. Edgewise conglomerate produced by submarine slumping.



B. Edgewise conglomerate produced by wave action.

A. Oolitic limestone of Conococheague (Allentown) formation. Bethlehem, Northampton County. Most spherules have upper half of white calcite and lower half dark.

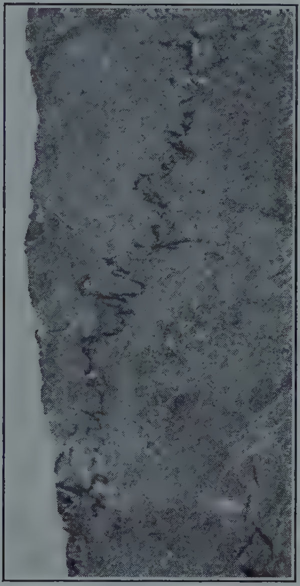
B. Oolitic Conococheague (Allentown) limestone with spherules removed by solution. East Allentown, Lehigh County.



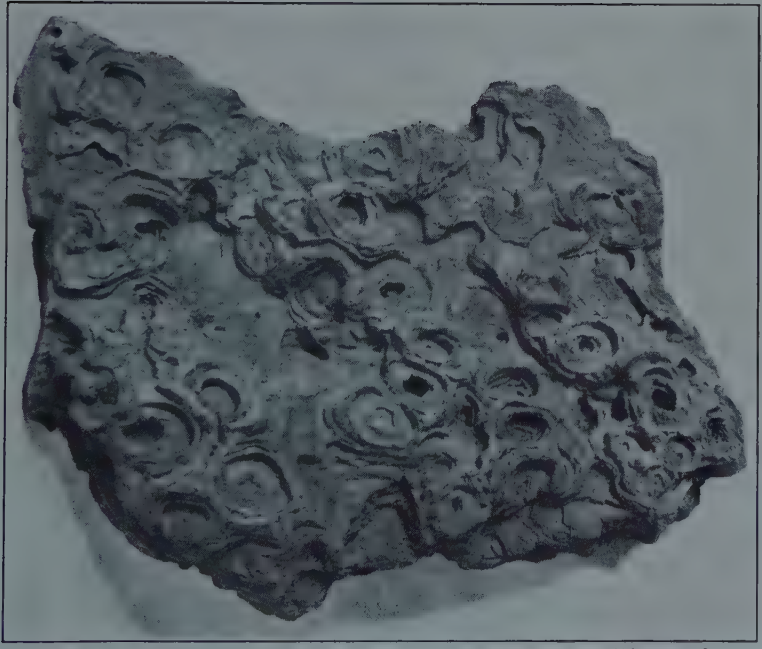
A. Fresh block of Loyalhanna limestone, Long Bridge, Westmoreland County. Cross-bedding indistinctly exhibited.

B. Weathered surface of Loyalhanna limestone showing prominent cross-bedding. Southeast of Mineral Point, Cambria County.

A. Stylolites in limestone from Carthage, Missouri.



B. Small and less pronounced stylolites in Pennsylvania limestone.



C. Weathered silicified specimens of *Cryptozoon proliferum* from Conococheague (Allentown) limestone, near Catasauqua, Northampton County.

A. Ripple-marked Tomstown limestone, Fountain Hill, Lehigh County.

B. Coarse ripple-marked Conococheague (Allentown) limestone, Raubsville, Northampton County.

in water. This is best accomplished by determining the volume of the specimens after saturation with water; that is, after they have soaked several days. This involves three weight determinations instead of two; namely, the dry weight in air, the saturated weight in air, and the weight of the saturated specimen in water. The apparent specific gravity is then computed by means of the formula

$G = \dfrac{W_1}{W_2 - W_3}$, in which W_1 = dry weight, W_2 = wet weight and

W_3 = weight suspended in water. By making this test in conjunction with the absorption test only one more weighing is necessary; that is, the weight suspended in water.

"The apparent specific gravity is of value in determining the actual unit weight of the stone and for computing the porosity. To determine the weight in pounds per cubic foot of the dry stone, one multiplies the apparent specific gravity by 62.5. The determination of the actual amount of pore space in a stone involves the use of the 'true specific gravity', which will be defined in the following section. For stones of fairly definite composition the apparent specific gravity value alone affords considerable information in regard to porosity. Most limestones are fairly pure calcium carbonate, and the actual or 'true specific gravity' may be assumed to be 2.72. The apparent specific gravity value of such limestones will be lower than 2.72, because of the pores or void spaces; hence the difference is a valuable index to porosity.

"The apparent specific gravity values of the limestones tested for this report varied from 1.87 to 2.69. The lowest value corresponds to a porosity of 31 per cent, while the highest indicates a porosity of slightly more than 1 per cent.

"Several of the limestones are dolomitic—that is, they contain a considerable amount of magnesium carbonate—and in such cases the true specific gravity may vary from 2.72 for a pure calcite to 2.86 for a true dolomite. Unless one knows approximately the percentage of magnesium carbonate present in a magnesium limestone, the apparent specific gravity determination alone affords little information concerning the porosity.

"The following range values for apparent specific gravity are given for comparison with other types of stone:

Basalt	2.9 — 3.2	Slate	2.6 — 2.8
Soapstone	2.8 — 3.0	Serpentine	2.5 — 2.84
Gneiss	2.7 — 3.0	Granite	2.6 — 2.7
Marble	2.7 — 2.86	Sandstone	2.2 — 2.7

"True specific gravity may be defined as the unit weight of the mineral constituents of the stone. It may be considered as the weight in grams of 1 cubic centimeter of stone which has the pores entirely filled with the same mineral substance as the original. The accurate determination of this property is more difficult than that of the apparent specific gravity.

"Determinations for this report were made by grinding the stone to a fine powder and making the measurements on the part passing a 200-mesh sieve. This is assumed to practically eliminate the pores,

so the task remaining is to accurately determine the volume of a known weight of the powdered material. This was done by means of a LeChatelier flask, which is a long-neck bottle with volumetric gradations on the neck. This is filled with gasoline or other suitable liquid to the lowest gradation, then a carefully weighed portion of the dry powder is poured in. The rise in level of the liquid is approximately the volume of the particles. There are sources of error in this measurement which have to be eliminated as far as possible. Considerable air is carried into the liquid with the powder, which should be removed before the volume reading is made. This is done by thoroughly agitating the powder in the liquid by swinging the flask around in a circle. Another source of error is that of temperature changes in the liquid between the times when the first and second volume readings are made. A difference of 1 or 2 degrees between these readings causes a large error, since the volume change of the entire liquid is included in that which is supposed to be only the volume of the powder. This is practically eliminated by setting the flask in a tank of water of constant temperature for several minutes before each volume reading. When the volume of a known weight of the powered material is determined, the true specific gravity value is computed by dividing this weight by the volume. The weight of powder used in these tests was 55 g. Check tests on the same material indicated a maximum variation of 0.03, and the usual range was 0.01.

"The true specific gravity values are used with the apparent specific gravity in computing the actual pore space. This is also of some value in the absence of a chemical analysis in classifying a limestone.

"The composition of the building limestones usually varies from fairly high calcium carbonate to various combinations of a calcium carbonate with magnesium carbonate up to the true dolomite $CaMg(CO_3)_2$. Since the true specific gravity of calcium carbonate is 2.72 and that of dolomite is 2.86, the determination of this value for any particular limestone affords considerable information as to the composition."

In general, limestones range from specific gravities of 2.58 to 2.75 with an average of about 2.64. These correspond to 161, 172, and 165 pounds per cubic foot respectively. Dolomites generally range from 2.69 to 2.90 in specific gravity with an average of about 2.72. These correspond to 168, 181, and 170 pounds per cubic foot respectively. Marbles average somewhat heavier than the unmetamorphosed rocks. The dolomitic varieties average about 2.77 specific gravity which means 177 pounds per cubic foot.

In making estimates of the tonnage of limestone in a given tract to a certain depth the practice of the writer is to use lower figures than those given in order to make allowance for cavities and rotten rock and clay pockets. The amount of reduction naturally depends upon the character of the information at hand. At times a figure as low as 160 pounds per cubic foot has been used.

The table at the close of the chapter furnishes data concerning Pennsylvania limestones and dolomites.

POROSITY AND ABSORPTION

It is important to know the porosity of rocks for on that depends the amount of absorption. The absorptive properties largely deter-

mine the durability under conditions of freezing temperatures. Those rocks of great porosity may become saturated with water and be broken into small bits on freezing. The porosity also measures the permeability. This topic is further discussed in the chapter on weathering.

In general, limestones have medium porosity in comparison with other consolidated rocks. The fresh igneous and metamorphic rocks have very low porosity, generally less than 1 per cent by volume. Shales and slates have about 4 per cent, limestones about 5, sandstones 10 to 15, loose sands, clays and soils 30 to 90 per cent porosity.

Many exact methods for determining porosity have been devised. A number of these are described by O. E. Meinzer in Water-Supply Paper 489 of the U. S. Geological Survey. The U. S. Bureau of Public Roads employs one of the simple methods which consists in determining "the gain in weight of the sample (10 pieces weighing 1,000 grams) after 24 hours' immersion in water."

The Bureau of Standards* describes the methods it employs as follows:

"The amount of pore space can be calculated when the apparent and true specific gravity values are known. This is usually expressed as a percentage by volume and is calculated by the formula

$$P = \frac{100}{t}(t\text{-}a),$$ in which t = the true specific gravity and a = the apparent specific gravity.

"The porosity of a stone is of interest in considering the probable weathering qualities. It represents the limit of absorption. A stone in the usual laboratory tests seldom absorbs an amount of water equal in volume to the total pore space."

"Absorption tests were made on the same sizes and shapes of specimens used in the compression tests. The dry weights were obtained after a drying period of at least 24 hours in an electric oven at 110°C. The absorption period was two weeks, during which time the specimens were entirely immersed in water at room temperatures. At the end of the absorption period the specimens were removed from the water one at a time, surface dried with a towel, and immediately weighed. In all cases the weights were determined to the nearest one-hundredth of a gram. Following the established custom the percentage of absorption was obtained by dividing the weight of absorbed water times 100 by the dry weight of the specimen. This value is termed the 'absorption by weight.' Since stones of different mineral composition are not of equal bulk density, it is evident that by this computation the values obtained are not strictly comparable. For this reason it is more logical to compute absorption results on the volume basis; that is, by dividing the volume of absorbed water by the volume of the specimen. Such results are entirely comparable for all types of stone.

"A considerable range in the absorption of limestones from different localities is indicated by the results, the lowest 'by volume' value being 0.04 per cent and the highest 24.8 per cent. Some of these

*Kessler, D. W. and Sligh, W. H., U. S. Bureau of Standards Tech. Paper 349, pp. 514-515, 517, Washington.

materials are very dense and approximate the texture of marble. In this class may be placed the Onondaga limestone, those materials from southwestern Missouri and the Illinois limestones. Considering the more typical building limestones, as those from Indiana, Kentucky, Alabama, Texas, and Minnesota, the absorption values usually range between 6 and 15 per cent by volume. The usual ranges for other types of stone computed on the same basis are as follows:

	Per cent
Sandstone	6-18
Slate	0.3-2.0
Granite	.4-1.8
Marble	.1-0.4"

The amount of absorption of many Pennsylvania limestones, dolomites, and marbles is given in the table at close of chapter.

CRUSHING STRENGTH

It is well recognized that it is necessary to know the crushing strength of rocks to be used in building bridges, etc. The methods employed in determining this property are all similar although varying considerably in details. The U. S. Bureau of Roads* describes its method as follows.

"This test is made on a cylindrical specimen 2 inches high and 2 inches in diameter. Both ends of the specimen are sawed at right angles to the axis of the cylinder and carefully ground to plane surfaces. The cylinder is then tested in compression in a suitable universal testing machine at a speed of 0.1 inch or less per minute. A small spherical bearing block is placed between the moving head of the machine and the specimen. At least two determinations are made and the average reported as the unit crushing strength, calculated in pounds per square inch. This test is made only when specifically requested and is considered not necessary in the usual examination of rock."

In general limestones can withstand a compressive strength of 15,000 to 30,000 pounds per square inch, dolomites from 25,000 to 40,000, whereas marbles crush with 8,000 to 12,000 pounds. There are apt to be wide variations depending upon the character of the stone. Those feebly cemented or very coarsely crystalline may fail at pressures of 3,000 pounds or even less. Some of the limestones near Annville, Lebanon Co., have decomposed to great depths to the extent that they can be crumbled in the hand.

In almost all stone buildings and bridges the load is so far below the crushing strength that the determinations are of little value. In the table at close of chapter, the crushing strengths of a number of Pennsylvania limestones, dolomites, and marbles are given.

The U. S. Bureau of Standards in Technologic Paper No. 349 describes the methods and results of determining compressive, transverse, and tensile strength of limestones, as well as shearing tests and elasticity. The latter tests are seldom made.

*Woolf, D. O., The results of physical tests on road-building rock: U. S. Dept. Agr., Miscl. Pub. No. 76, p. 3, Washington, 1930.

Results of tests of road-building rock of Pennsylvania to January 1, 1928, by the Bureau of Tests, U. S. Department of Agriculture

Town or City	County	Material	Crushing strength	Weight per cubic foot	Ab-sorption	Per cent of wear	French co-efficient of wear	Hard-ness	Tough-ness
			lbs/sq.in.	pounds	lbs/cu.ft.				
Bittinger	Adams	Limestone	[2]	172	.20	4.9	8.2	14.2	9
Cumberland	Do	Limestone	[2]	165	1.25	2.0	20.0	17.2	25
Hanover (near)	Do	Marble	[2]	[illegible]	.11	4.0	10.0	14.7	8
Do	Do	Limestone	[2]	175	.21	4.1	9.8	16.0	7
Do	Do	Marble	[2]	168	.37	5.5	6.9	13.3	3
Do	Do	do	[2]	168	.37	5.1	7.8	11.0	6
Do	Do	Siliceous limestone	[2]	178	.21	3.5	11.4	17.7	9
McSherrystown	Do	Marble	[2]	168	.32	4.7	8.5	12.4	5
Oxford Township	Do	Dolomite	[2]	172	.43	3.9	10.3	17.7	16
Coraopolis (near)	Allegheny	Limestone	[2]	165	.83	5.9	6.8	16.7	12
Oakdale	Do	do	[2]	172	.29	4.2	9.5	16.4	7
Pittsburgh	Do	do	[2]	172	.60	[2]	[2]	16.6	9
Do	Do	do	[2]	168	.27	4.5	8.9	15.3	3
Sewickley Township	Do	Siliceous limestone	[2]	168	1.24	3.8	10.5	14.1	12
Do	Do	Limestone	[2]	172	.36	4.5	8.9	14.3	11
Freeport (near)	Armstrong	Siliceous limestone	[2]	168	.58	2.9	13.8	16.6	9
Kittanning	Do	Limestone	[2]	165	1.21	4.8	8.3	15.5	8
Do	Do	do	[2]	168	.35	4.9	8.2	15.7	8
Do	Do	do	[2]	165	.79	4.8	8.3	16.4	9
Parkers Landing	Do	do	19,470	161	.88	4.2	9.5	15.3	6
Templeton	Do	do	[2]	168	.52	5.1	7.8	14.8	6
Beaver	Beaver	do	[2]	168	.72	6.7	6.0	14.7	6
Bedford	Bedford	do	[2]	168	.72	4.3	9.3	16.5	7
Hyndman	Do	do	[2]	172	.45	3.4	11.8	17.2	15
Do	Do	do	24,150	168	.22	2.9	13.8	14.3	6
Do	Do	Siliceous limestone	21,860	168	.22	4.1	9.8	16.5	10
Loysburg	Do	Dolomitic limestone	[2]	168	.53	4.2	9.5	[2]	[2]
Do	Do	Dolomite	[2]	178	.83	3.4	11.8	15.8	11
Waterside	Do	Limestone	[2]	172	.31	3.5	11.4	16.7	10
Reading	Berks	Dolomite	[2]	168	.12	3.6	11.1	16.2	11
Do	Do	Argillaceous dolomite	[2]	168	.39	3.3	12.1	17.7	5
Do	Do	Dolomite	[2]	178	.42	5.7	7.0	[2]	[2]
Tuckerton (near)	Do	Siliceous limestone	[2]	170	.12	3.7	10.8	15.7	10
Allegheny Township	Blair	Limestone	[2]	168	.35	4.9	8.2	13.7	5
Altoona (near)	Do	do	[2]	168	.63	5.4	7.4	11.3	8
Altoona	Do	do	[2]	168	.39	3.2	12.5	14.2	7
Do	Do	do	[2]	168	.32	2.8	14.3	16.7	11
Do	Do	do	[2]	168	.91	4.3	9.3	15.3	6

Results of tests of road-building rock of Pennsylvania to January 1, 1928, by the Bureau of Tests, U. S. Department of Agriculture—Continued

Town or City	County	Material	Crushing strength	Weight per cubic foot	Absorption	Per cent of wear	French coefficient of wear	Hardness	Toughness
			lbs/sq.in.	pounds	lbs/cu.ft.				
Catharine Township	Blair	Siliceous limestone	[2]	168	.46	3.6	11.1	16.7	22
Eldorado (near)	Do	Dolomite	[2]	178	.41	3.3	12.1	16.8	10
Hollidaysburg	Do	do	[2]	172	.84	3.3	12.1	17.2	11
Do	Do	Limestone	[2]	172	.49	3.7	10.8	17.3	20
Do	Do	do	[2]	172	.80	3.0	13.3	17.1	16
Juniata	Do	Crystalline limestone	15,430	168	.40	5.9	6.8	13.7	4
Do	Do	Argillaceous limestone	20,875	168	.45	5.9	6.8	[2]	[2]
Tyrone Township	Do	Limestone	[2]	178	.26	3.1	12.9	16.5	10
[1]	Do	do	[2]	168	.10	3.2	12.5	16.5	11
Burlington Township	Bradford	Argillaceous limestone	[2]	168	.94	4.9	8.2	15.3	7
Camptown	Do	Limestone	[2]	168	.68	4.2	9.5	15.2	8
East Smithfield	Do	Fossiliferous limestone	[2]	168	.40	6.8	5.9	15.7	10
Sheshequin Township	Do	Limestone	[2]	165	.22	6.7	6.0	16.0	10
Do	Do	do	[2]	168	.32	5.3	7.5	16.8	11
Shores Hill	Do	Siliceous limestone	[2]	162	1.51	4.2	9.5	15.6	8
Wells	Do	do	[2]	168	.63	3.5	11.4	15.9	14
Wyalusing Township	Do	Limestone	[2]	168	.64	4.3	9.3	15.2	7
Wyalusing	Do	do	[2]	169	.39	3.7	10.8	16.3	4
Do	Do	Fossiliferous dolomite	[2]	168	.63	4.7	8.5	17.9	22
Wysox Township	Do	Calcareous sandstone	[2]	165	.89	2.9	13.8	17.3	9
Do	Do	Siliceous limestone	[2]	168	.84	3.9	10.3	16.0	9
Do	Do	do	[2]	168	.49	3.1	12.9	16.7	12
Do	Do	Limestone	[2]	168	.26	5.3	7.5	14.3	7
Do	Do	do	[2]	168	.20	3.7	10.8	17.8	16
Do	Do	do	[2]	165	.24	3.3	12.1	17.0	13
Rushland	Bucks	Siliceous limestone	[2]	168	.49	2.3	17.4	17.0	20
Do	Do	do	[2]	172	.39	2.5	16.0	17.5	22
[1]	Do	Limestone	[2]	175	1.32	4.2	9.5	16.0	10
West Winfield	Butler	do	[2]	168	.23	3.7	10.8	16.1	6
Johnstown	Cambria	do	[2]	168	.33	2.8	14.3	16.8	14
East Taylor Township	Do	Calcareous sandstone	[2]	169	.38	2.8	14.2	17.5	11
Bellefonte	Centre	Limestone	[2]	168	.31	5.8	6.9	16.3	11
Do	Do	do	[2]	168	.46	3.7	10.8	14.7	6
Do	Do	Calcareous sandstone	[2]	165	.75	4.5	8.9	15.3	7
Spring Township	Do	Limestone	[2]	168	.45	4.5	8.9	13.6	6
Avondale	Chester	Crystalline limestone	[2]	172	.41	13.2	3.0	14.0	3
Do	Do	Marble	[2]	172	.30	4.5	8.9	14.7	5
Cedar Hollow	Do	Dolomite	[2]	178	.16	3.8	10.5	[2]	[2]
Do	Do	do	[2]	178	.17	4.5	8.9	16.3	8

Do	Do	Dolomite Marble	[2]	175	.38	4.7	8.5	16.0	10
Coatesville	Do	Marble	[2]	178	.16	3.8	10.5	15.9	9
Do	Do	Limestone	[2]	175	.22	4.7	8.5	15.4	9
Do	Do	Marble	[2]	172	.24	5.9	6.8	11.8	5
Devault	Do	Dolomitic marble	[2]	170	.70	7.7	5.2	14.0	5
Do	Do	Dolomite	[1]	177	.51	4.0	10.0	14.0	8
Do	Do	do	39,250	178	.25	5.0	8.0	15.3	10
East Whiteland	Do	do	[2]	178	.20	4.2	9.5	14.9	7
Do	Do	Dolomitic limestone	[2]	178	.31	3.9	10.3	15.7	7
Exton	Do	Dolomite	[2]	178	.48	4.2	9.5	16.3	9
Howellsville	Do	Marble	[2]	175	.10	4.2	9.5	13.0	8
Do	Do	do	[2]	173	.36	4.3	9.3	[2]	[2]
Do	Do	do	[2]	175	.31	4.6	8.7	14.0	5
Do	Do	Dolomite marble	[2]	172	.10	5.7	7.0	14.0	4
Knickerbocker	Do	Limestone	[2]	172	.37	4.0	10.0	17.1	15
Do	Do	Dolomite	[2]	175	.58	4.1	9.8	15.3	7
West Grove (near)	Do	Crystalline limestone	[2]	172	.31	4.2	9.5	13.8	6
[1]	Do	Dolomite marble	[2]	178	.22	2.9	13.8	14.8	8
Fryburg	Clarion	Limestone	[2]	168	.71	4.7	8.5	15.5	6
Leeper	Do	do	[2]	168	.42	4.4	9.1	14.5	23
[1]	Do	do	[2]	168	.67	4.4	9.1	16.7	9
Lamar Township	Clinton	do	[2]	168	.21	5.0	8.0	15.9	10
Lock Haven	Do	do	[2]	168	.61	4.5	8.9	13.8	8
Do	Do	do	[2]	168	1.38	6.5	6.2	8.4	4
Salona	Do	do	[2]	168	.42	5.6	7.1	15.0	5
Do	Do	Argillaceous limestone	18,710	168	.06	4.3	9.3	15.3	8
Berwick	Columbia	Calcareous slate	[2]	172	.57	10.0	4.0	7.3	10
Espy	Do	Argillaceous dolomite	[2]	175	.77	4.0	10.0	15.6	14
Limeridge	Do	Limestone	[2]	168	.33	3.6	11.1	16.3	16
Bowmansdale	Cumberland	do	[2]	168	.28	4.1	9.8	17.2	10
Carlisle	Do	do	[2]	168	.57	7.1	5.6	15.7	10
Dickinson Township	Do	do	[2]	172	.33	5.2	7.7	15.0	8
Lemoyne	Do	do	[2]	172	.42	3.4	11.8	17.4	9
Do	Do	do	[2]	174	.26	4.2	9.5	18.3	12
Mechanicsburg	Do	do	[2]	172	.24	3.3	12.1	16.1	8
Mechanicsburg (near)	Do	Siliceous marble	[2]	168	.14	5.5	7.3	15.2	2
West Fairview	Do	Calcareous sandstone	[2]	168	.31	3.6	11.1	15.7	17
West Fairview (near)	Do	do	[2]	172	.22	4.2	9.5	17.0	14
Harrisburg	Dauphin	Dolomite	[2]	172	.47	4.2	9.5	18.0	13
Do	Do	do	[2]	175	.24	2.9	13.8	17.9	12
Do	Do	Calcareous sandstone	[2]	168	.26	3.5	11.4	15.2	13
Highspire	Do	Limestone	[2]	168	.59	3.9	10.3	13.3	6
Hummelstown	Do	Dolomitic limestone	[2]	175	.46	3.7	10.8	17.7	7
Do	Do	do	[2]	178	.23	4.1	9.8	17.3	10
Do (2 miles from)	Do	Calcareous sandstone	[2]	168	.53	4.2	9.5	16.0	19
Paxtang	Do	Limestone	[2]	172	.21	3.2	12.5	17.3	14
Steelton	Do	Dolomite	[2]	147	.29	4.2	9.5	18.3	18
[1]	Do	Dolomitic marble	[2]	175	.45	3.0	13.3	17.3	9
[1]	Do	Limestone	8,510	168	.57	5.5	7.3	14.2	2
[1]	Do	do	19,250	[illegible]	.27	5.4	7.4	15.0	[2]
[1]	Do	Siliceous dolomite	9,638	175	.28	3.6	11.1	16.3	8

Results of tests of road-building rock of Pennsylvania to January 1, 1928, by the Bureau of Tests, U. S. Department of Agriculture—Continued

Town or City	County	Material	Crushing strength	Weight per cubic foot	Ab-sorption	Per cent of wear	French co-efficient of wear	Hard-ness	Tough-ness
			lbs/sq.in.	pounds	lbs/cu.ft.				
Kersey	Elk	Limestone	[2]	172	.11	3.8	10.5	[2]	[2]
St. Marys (near)	Do	Argillaceous limestone	[2]	168	.49	5.0	8.0	16.0	5
Bidwell	Fayette	Limestone	13,450	168	.90	3.0	13.3	15.7	12
Bluestone	Do	Calcareous sandstone	[2]	168	.20	2.6	15.4	18.0	11
Brownsville (near)	Do	Limestone	[2]	168	.51	3.5	11.4	17.6	12
Caspar:s	Do	Siliceous limestone	31,090	167	.18	2.7	14.8	16.0	14
Do	Do	do	[2]	166	.57	2.4	16.7	17.7	15
Do	Do	do	[2]	167	.40	3.1	12.9	17.5	9
Connellsville	Do	do	[2]	168	.06	2.5	16.0	16.3	18
Do (3 m. east of)	Do	Limestone	[2]	168	.24	2.4	16.7	17.6	13
Do (east of)	Do	do	26,050	168	.47	3.2	12.5	17.3	12
Do	Do	Siliceous limestone	[2]	168	.46	2.8	14.3	17.7	13
Cool Spring	Do	do	[2]	165	.19	3.0	13.3	18.2	11
Dunbar Township	Do	do	[2]	168	.27	2.4	16.7	17.1	15
Dunbar	Do	Limestone	[2]	168	.26	2.3	17.4	18.3	14
Do	Do	do	[2]	168	.34	2.3	17.4	17.0	9
Do (6 miles from)	Do	do	[2]	168	.34	3.6	11.1	16.6	7
Evans	Do	do	[2]	168	2.16	3.1	12.9	15.5	17
Farmington	Do	do	[2]	168	.52	4.0	10.0	15.7	8
Fayette City	Do	do	[2]	168	.20	5.5	7.3	16.3	4
Humberston	Do	do	[2]	168	.41	2.6	15.4	16.0	9
Indian Creek	Do	Calcareous sandstone	37,740	168	.28	3.3	12.1	17.0	17
Masontown	Do	Limestone	[2]	168	2.42	3.9	10.3	16.5	9
Somerfield (near)	Do	do	[2]	168	.80	5.5	7.3	14.3	2
Do	Do	do	[2]	168	.65	3.1	12.9	15.9	10
Do (3 miles from)	Do	do	[2]	168	.46	2.6	15.4	16.2	9
Uniontown	Do	do	[2]	168	.70	4.4	9.1	13.0	5
Do	Do	Siliceous limestone	[2]	168	.15	2.9	13.8	17.3	11
Do	Do	do	[2]	168	.32	3.4	11.8	17.8	11
Do	Do	Limestone	[2]	168	.23	3.5	11.4	15.7	7
Uniontown (7 miles from)	Do	do	[2]	168	.72	5.2	7.7	13.5	5
Do (near)	Do	Siliceous limestone	[2]	168	.37	3.5	11.4	11.2	15
Mercersburg	Franklin	Limestone	[2]	[illegible]	.33	4.3	9.3	15.8	9
Montgomery Township	Do	Dolomite	[2]	178	.52	3.2	12.5	17.9	10
Richmond Furnace	Do	Limestone	[2]	175	.21	2.4	16.7	17.3	18
Waynesboro (near)	Do	Dolomitic limestone	[2]	175	.77	3.6	11.1	17.5	9
Brady Township	Huntingdon	Limestone	[2]	168	.41	5.0	8.0	15.5	5
Do	Do	do	[2]	168	.52	4.1	9.8	15.3	5

Do	Do	do	[2]	172	.24	4.0	10.0	15.0	9
Do	Do	do	[2]	168	.37	5.4	7.4	16.0	7
Huntingdon	Do	do	[2]	175	.22	3.1	12.9	16.7	14
Do	Do	Siliceous limestone	[2]	168	.53	4.5	8.9	[2]	[2]
Do	Do	Limestone	[2]	168	.42	4.8	8.3	15.6	7
Do	Do	Argillaceous limestone	[2]	172	.52	[2]	[2]	16.0	4
Mill Creek	Do	Limestone	[2]	168	.94	4.8	8.3	15.2	5
Mount Union	Do	do	[2]	168	.62	4.2	9.5	14.4	6
Shirley Township	Do	do	[2]	168	.36	4.1	9.8	15.2	6
Union Furnace	Do	Dolomite	[2]	178	.16	3.5	11.4	16.1	11
Do	Do	Limestone	[2]	168	.23	3.8	10.5	16.2	7
Do	Do	Marble	[2]	173	.33	3.9	10.3	15.7	7
Warriors Mark	Do	Siliceous limestone	[2]	175	.52	2.5	16.0	18.2	14
[1]	Do	Limestone	[2]	168	.21	6.6	6.1	11.0	4
[1]	Do	Sedimentary limestone	[2]	168	.57	3.7	10.8	15.8	6
[1]	Do	do	[2]	168	.24	4.5	8.9	17.3	6
[1]	Do	Carbonaceous limestone	[2]	169	.31	5.0	8.0	16.3	5
Indiana	Indiana	Limestone	[2]	168	.06	2.7	14.8	16.8	13
Mifflin	Juniata	Argillaceous limestone	[2]	172	.31	4.4	9.1	16.3	9
Gap	Lancaster	Micaceous marble	[2]	172	.29	5.0	8.0	11.5	7
Do	Do	Dolomitic marble	[2]	181	.22	7.6	5.3	12.7	4
Do	Do	do	[2]	181	.23	4.7	8.5	11.8	4
Do	Do	do	[2]	178	.30	4.8	8.3	13.6	6
Lancaster	Do	Calcareous schist	[2]	172	.40	4.0	10.0	15.5	5
Lititz	Do	Limestone	[2]	168	.17	5.0	8.0	12.7	4
Do	Do	Marble	[2]	172	.08	4.2	9.5	11.5	5
Maytown	Do	Limestone	[2]	165	.33	6.0	6.7	15.8	5
Millway	Do	do	[2]	172	.18	3.9	10.3	16.5	8
Quarryville	Do	Marble	[2]	168	.20	5.2	7.7	14.5	5
Refton	Do	Dolomite	[2]	178	.24	3.9	10.3	11.8	9
Do	Do	do	[2]	178	1.14	4.7	8.5	12.7	6
Rheems	Do	Limestone	[2]	168	.46	5.8	6.9	15.2	14
Do	Do	do	[2]	174	.52	4.9	8.2	16.7	16
Rothsville	Do	Argillaceous dolomite	[2]	178	.35	4.5	8.9	16.0	4
Do	Do	Limestone	[2]	178	.16	4.3	9.3	16.9	10
Salisbury	Do	Siliceous limestone	[2]	168	.37	3.7	10.8	14.3	9
Do	Do	Calcareous schist	[2]	181	.28	15.2	2.6	[2]	[2]
Strasburg Township	Do	Dolomite	[2]	178	.45	5.0	8.0	14.3	4
Chewton	Lawrence	Limestone	[2]	168	.39	4.4	9.1	15.8	8
Ellwood City (near)	Do	do	[2]	168	.64	4.5	8.9	[2]	[2]
Rock Point (near)	Do	do	[2]	168	.48	5.1	7.8	15.6	7
Walford	Do	do	27,500	168	.25	4.9	8.2	16.5	7
Wayne Township	Do	do	[2]	168	.45	3.9	10.3	16.5	9
Annville	Lebanon	Carbonaceous limestone	[2]	175	.83	2.9	13.8	17.0	7
Cornwall	Do	Dolomitic limestone	[2]	178	.50	4.1	9.8	13.7	8
Lebanon	Do	Dolomite	[2]	175	.48	3.7	10.8	17.6	20
Do	Do	Siliceous limestone	[2]	172	.20	3.8	10.5	16.1	9
Do	Do	Argillaceous limestone	[2]	168	.34	4.3	9.3	12.9	9
Do	Do	Siliceous limestone	[2]	169	.20	4.3	9.3	15.8	3
Do	Do	Argillaceous limestone	[2]	172	.17	3.2	12.5	14.7	7
Sheridan	Do	Marble	[2]	172	.12	3.6	11.1	16.5	6
South Lebanon Township	Do	Limestone	[2]	168	.31	4.1	9.8	13.3	6

Results of tests of road-building rock of Pennsylvania to January 1, 1928, by the Bureau of Tests, U. S. Department of Agriculture—Continued

Town or City	County	Material	Crushing strength	Weight per cubic foot	Ab-sorption	Per cent of wear	French co-efficient of wear	Hard-ness	Tough-ness
			lbs/sq.in.	pounds	lbs/cu.ft.				
Allentown	Lehigh	Dolomite	2	175	.07	6.9	5.8	18.6	20
Do	Do	do	2	2	2	2	2	16.4	10
Catasauqua	Do	Argillaceous dolomite	2	175	.17	2.4	16.7	2	2
Duryea	Luzerne	Calcareous sandstone	2	168	.46	2.4	16.7	15.5	10
Do	Do	do	2	167	.41	3.4	11.8	16.7	13
Pittston (near)	Do	do	2	165	.55	3.0	13.3	16.3	12
Do	Do	do	2	168	.35	2.9	13.8	18.6	7
Cogan House Township	Lycoming	do	2	165	1.09	4.8	8.3	13.0	7
Hughesville	Do	Argillaceous sandstone	2	168	.80	3.3	12.1	12.3	13
Jersey Shore	Do	Limestone	2	172	.38	4.1	9.8	17.3	10
Do	Do	Siliceous limestone	20,360	166	.44	2.6	15.4	18.2	9
Do	Do	Limestone	23,030	167	.37	3.1	12.9	18.8	9
Jersey Shore (near)	Do	Limestone	2	168	2	5.1	7.8	14.3	8
Do	Do	Argillaceous limestone	28,585	165	.58	3.8	10.5	18.0	22
Do	Do	do	26,860	168	.56	4.2	9.5	17.3	21
Do	Do	do	18,610	172	1.26	5.4	7.4	12.5	14
Do	Do	Limestone	22,930	168	.44	4.6	8.7	16.0	11
Do	Do	do	21,900	172	.43	3.0	13.3	16.5	8
Do	Do	do	14,160	168	.65	3.2	12.5	14.7	7
Lime Bluff	Do	Argillaceous limestone	21,160	168	.27	7.3	5.5	14.7	8
Linden	Do	Dolomite	2	175	.51	5.4	7.4	15.3	10
Lower Fairfield Township	Do	Limestone	2	168	.18	4.7	8.3	16.2	8
Loyalsock Township	Do	Carbonaceous limestone	2	168	1.47	4.1	9.8	16.8	8
Montgomery (near)	Do	Limestone	2	172	.78	4.9	8.2	8.7	9
Montoursville	Do	Calcareous chert	2	165	.96	4.9	8.2	19.7	3
Do	Do	Argillaceous limestone	23,460	168	.10	6.6	6.1	16.2	6
Do (near)	Do	Limestone	2	169	.18	7.5	5.3	15.3	5
Muncy Township	Do	Siliceous limestone	2	172	.22	7.4	5.4	13.0	6
Do	Do	Limestone	2	168	.47	6.0	6.7	15.7	4
Porter Township	Do	do	2	168	.58	4.6	8.7	16.2	8
Williamsport	Do	Calcareous shale	2	172	.87	2	2	13.9	8
Do	Do	Limestone	2	168	.24	5.8	6.9	16.4	8
Do	Do	Argillaceous limestone	2	168	.40	4.8	8.3	17.3	8
Lewistown	Mifflin	Limestone	2	168	.29	4.1	9.8	18.8	18
Do	Do	Argillaceous limestone	2	168	.35	2.3	17.4	16.8	7
Milroy	Do	Siliceous limestone	2	172	.42	3.0	13.3	17.0	17
Naginey	Do	Limestone	2	168	.88	4.9	8.2	15.0	10
Reedsville	Do	do	2	165	.83	5.5	7.3	11.9	4

Conshohocken (near)	Montgomery	do	[2]	178	.53	4.2	9.5	16.0	8
Green Lane	Do	Calcareous sandstone	[2]	168	1.85	2.0	20.0	18.7	23
Hendricks	Do	Calcareous slate	[2]	165	1.24	2.2	18.2	16.4	8
Huber Heights (near Norristown)	Do	Siliceous limestone	[2]	175	.50	3.4	11.8	17.4	10
Ivy Rock	Do	Dolomite	[2]	175	.82	4.1	9.8	14.7	8
Do	Do	Dolomitic marble	[2]	177	.26	4.9	8.2	15.3	7
Norristown	Do	do	[2]	178	.32	4.1	9.8	15.9	6
Norristown (near)	Do	do	[2]	178	.26	4.5	8.9	14.5	5
Phoenixville (near)	Do	Siliceous limestone	[2]	168	.80	3.0	13.3	17.2	14
Plymouth Meeting	Do	Dolomitic marble	[2]	178	.54	4.0	10.0	12.7	6
Plymouth Township	Do	do	[2]	178	.22	3.6	11.1	15.8	8
Do	Do	do	[2]	178	.24	3.4	11.8	17.0	9
Port Kennedy	Do	Dolomite	[2]	178	.22	4.2	9.5	9.0	11
Do	Do	Dolomitic marble	[2]	168	.12	6.3	6.3	14.8	5
[1]	Do	do	[2]	178	.21	7.3	5.5	14.3	3
[1]	Do	Siliceous limestone	[2]	169	.35	2.3	17.4	17.7	19
Bath	Northampton	Siliceous dolomite	[2]	175	.10	2.1	19.0	17.7	13
Bethlehem (near)	Do	Dolomite	38,949	174	.04	4.9	8.2	15.0	10
Do	Do	Limestone	18,990	171	.14	5.2	7.7	14.7	7
Do	Do	do	21,440	167	.28	6.2	6.5	11.8	8
Easton	Do	do	[2]	178	.21	3.5	11.4	15.4	10
Do	Do	Dolomite	[2]	175	.26	3.6	11.1	17.9	17
Nazareth	Do	do	[2]	175	.22	2.4	16.7	17.4	27
Do	Do	Argillaceous limestone	[2]	165	1.44	4.2	9.5	10.9	6
Redington	Do	Dolomite	[2]	178	.08	5.5	7.3	[2]	[2]
Siegfried	Do	do	[2]	175	.30	2.5	16.0	17.3	19
Do	Do	do	[2]	175	.23	2.8	14.3	17.4	12
Dewalt	Northumberland	Limestone	[2]	165	.40	3.8	10.5	15.6	9
Do	Do	do	[2]	168	.36	4.6	8.7	15.5	8
McEwensville	Do	Siliceous limestone	[2]	159	2.01	10.0	4.0	16.6	9
Sunbury (near)	Do	Limestone	[2]	168	.63	5.6	7.1	15.8	7
Do	Do	Argillaceous limestone	[2]	168	.21	10.0	4.0	13.3	4
Turbotville	Do	Limestone	[2]	168	.49	6.1	6.6	17.0	10
Watsontown	Do	do	[2]	172	.32	3.3	12.1	13.2	7
[1]	Do	do	[2]	168	.82	6.0	6.7	14.7	5
Oreland (near)	Philadelphia	Dolomite	[2]	178	.40	6.4	6.2	[2]	[2]
Philadelphia	Do	Calcareous slate	[2]	168	.24	5.1	7.8	[2]	[2]
Do	Do	Marble	[2]	172	.59	5.0	8.0	13.5	8
Sittler	Schuylkill	Calcareous shale	[2]	168	.61	5.4	7.4	15.0	8
Shamokin Dam	Snyder	Chert and limestone	[2]	168	2.72	4.1	9.8	14.7	7
Boswell	Somerset	Limestone	[2]	168	1.05	4.4	9.1	17.3	10
Do	Do	Argillaceous limestone	[2]	172	.39	4.9	8.2	17.0	14
Confluence	Do	Calcareous sandstone	24,790	168	.34	3.6	11.1	16.7	7
Paint Township	Do	Impure limestone	[2]	178	.27	3.5	11.4	16.9	15
Somerfield	Do	Limestone	[2]	168	.64	3.4	11.8	15.7	14
Somerfield	Do	Limestone	[2]	168	.53	4.3	9.3	14.0	6
Susquehanna	Susquehanna	do	[2]	168	.30	3.8	10.5	13.9	6
Delmar Township	Tioga	Calcareous sandstone	[2]	168	.78	3.3	12.1	16.3	7
Duncan Township	Do	do	[2]	172	.40	4.2	9.5	16.3	13
Mansfield	Do	Siliceous limestone	[2]	168	.36	5.0	8.0	12.5	5
Wellsboro	Do	Limestone	[2]	165	1.15	4.7	8.5	16.7	12

Results of tests of road-building rock of Pennsylvania to January 1, 1928, by the Bureau of Tests, U. S. Department of Agriculture—Concluded

Town or City	County	Material	Crushing strength	Weight per cubic foot	Ab-sorption	Per cent of wear	French co-efficient of wear	Hard-ness	Tough ness
			lbs/sq.in.	pounds	lbs/cu.ft.				
Lewisburg	Union	Limestone	[2]	168	1.23	4.5	8.9	14.7	5
Do	Do	do	[2]	168	.81	3.9	10.3	15.7	4
Do	Do	do	[2]	168	.73	4.9	8.2	14.8	5
Mifflinburg	Do	Argillaceous limestone	[2]	168	.19	5.5	7.3	14.8	8
Do	Do	Limestone	[2]	168	.39	5.3	7.5	15.6	6
Monongahela	Washington	do	[2]	172	.24	4.0	10.0	15.8	12
Do	Do	do	[2]	162	3.19	3.3	12.1	16.3	16
Washington	Do	Argillaceous limestone	[2]	168	.73	2.8	14.3	16.5	12
Do	Do	Dolomitic limestone	[2]	175	.95	2.6	15.4	16.8	14
Blairsville Intersection	Westmoreland	Siliceous limestone	32,560	168	.41	2.1	19.0	17.2	19
Greensburg	Do	Limestone	[2]	168	1.01	3.7	10.8	16.9	10
Ligonier	Do	Siliceous limestone	22,500	168	.16	2.6	15.4	17.3	8
Long Bridge	Do	do	[2]	168	.21	[2]	[2]	17.0	13
McKeesport (near)	Do	Limestone	[2]	172	.96	3.2	12.5	17.0	13
Mount Pleasant	Do	do	[2]	165	.57	4.2	9.5	16.9	8
North Huntingdon Township	Do	do	[2]	165	1.01	4.9	8.2	16.7	8
Saltsburg	Do	Calcareous sandstone	[2]	165	1.64	3.6	11.1	9.9	11
Smithton	Do	Limestone	[2]	171	.20	4.2	9.5	16.7	11
[1]	Do	Siliceous limestone	[2]	168	.33	2.3	17.4	16.7	8
Campbell	York	Limestone	[2]	178	.22	3.9	10.3	17.1	6
Emigsville	Do	Dolomitic marble	[2]	175	.15	4.6	8.7	14.3	7
Hanover	Do	Siliceous marble	[2]	168	.49	4.3	9.3	15.8	7
Do	Do	do dolomite	[2]	178	.16	4.0	10.0	17.7	12
Hellam	Do	Crystalline limestone	[2]	172	.18	3.1	2.9	16.7	7
Shock's Mills	Do	Limestone	[2]	172	.15	5.7	7.0	9.0	4
Spring Forge	Do	do	[2]	178	.87	3.2	12.5	[2]	[2]
West York	Do	Argillaceous limestone	[2]	175	.29	2.8	14.3	17.3	28
Wrightsville	Do	Dolomitic marble	[2]	175	14	2.6	15.4	17.1	13
York	Do	Limestone	[2]	172	.32	4.5	8.9	14.0	5
Do	Do	Crystalline limestone	[2]	172	.19	3.1	12.9	14.8	9
Do	Do	Carbonaceous limestone	[2]	168	.44	4.8	8.3	14.8	7
Do	Do	Dolomitic marble	[2]	173	.19	3.4	11.8	15.3	9
Do	Do	Crystalline dolomite	[2]	175	.30	6.1	6.6	15.6	5
Do	Do	Dolomitic marble	[2]	178	.16	8.2	4.9	14.2	5
York (near)	Do	Limestone	[2]	165	.19	5.8	6.9	8.8	6
Do	Do	do	[2]	168	.48	4.3	9.3	14.3	8

[1] Exact location not known.
[2] Test not made.

*Crushing strength of Montgomery County limestone.**

Kind of stone	Locality	Size of cube	Position	Strength per sq. in.	Remarks
Limestone (marble)	Montgomery County, Pa.	6.55x 6.05x 6.02	Bed	13,700	
Do	do	6.50x 6.05x 6.03	End	10,120	
Do	do	6.04x 6.00x 6.01	End	9,590	Probable reduction in strength from uneven bearing.
Do	do	6.60x 6.01x 6.0	Bed	10,940	
Do	do	6.4x 6.35x 6.02	Bed	11,470	Failed immediately after first signs of rapid yielding.
Do	do	6.00x 6.40x 6.02	End	10,420	No signs of failure until block burst.
Limestone	Conshohocken, Pa.	5.94x 5.90x 5.92	End	14,090	Block split up along stratification.
Do	do	5.92x 5.85x 5.92	Bed	16,340	Failed immediately.

* Table from Merrill, G. P., Stones for building and decoration.

CHAPTER III

ORIGIN OF LIMESTONES, DOLOMITES, AND MARBLES

Limestones are world-wide in their distribution and have been the object of careful investigation by geologists of all countries. The literature pertaining to their origin is so extensive that it is not possible to summarize it properly in this volume. It is well recognized that limestones vary widely in their chemical, mineralogical, and physical characteristics as described on previous pages and that these varying features represent different processes of sedimentation. The problems of origin are concerned with the places of origin, the primary source of the chemical constituents, and the processes that have resulted in the deposition of the calcareous materials.

PLACES OF ORIGIN

At one time it was generally believed that limestones represent deposition in ocean waters remote from land and in relatively deep water although not the deepest portions of the oceanic basins. The reasons for attributing them to such localities were the absence of materials derived from the land and the uniformity and wide lateral extent of limestone beds in comparison with shales, sandstones, and conglomerates. This belief has been gradually changing until now it is believed that practically all of the limestones now forming our continents and available for examination were deposited in shallow water. Since shallow water is rarely found in any of our ocean basins except close to land, it therefore appears probable that they are mainly near-shore deposits. The evidences for shallow-water deposition of our Pennsylvania limestones have been presented in a previous chapter describing the textural and structural features, most of which could only be developed in water sufficiently shallow to permit waves and currents to disturb the sediments. Wave and ripple marks, cross-bedding, intraformational conglomerates, mud cracks, etc. are all common features of limestones and all characteristic of shallow water deposition.

It is perhaps natural for us to think that all near-shore deposits should contain considerable terrigenous (land-derived) material, yet this is not necessarily the case. A continental land mass with the shores low and swampy contributes very little to the ocean except in solution, so we are forced to believe that our purest limestones that present evidences of shallow water deposition must have formed near a land mass of low relief or on broad shelves of slight submergence, perhaps extending to a considerable distance from the shore.

The recent study of the insoluble residues of limestones and dolomites has shown in practically every case more minute water or wind worn land-derived minerals than previously suspected. These reached the places where the calcareous oozes were accumulating by either water or air currents. Where they constitute a very small amount and are extremely fine, it is probable that winds were mainly responsible for their transportation from a dry land surface.

In many places within the Pennsylvania limestones some sandy limestone beds or even definite thin sandstones are interbedded with

the purer limestone strata. Such occurrences may be the result of heavy sand or dust storms on land, carrying much material out to sea, but more probably were produced when unusually heavy floods on land carried sand across the low coastal belt to the ocean.

Thus far only marine limestones have been considered, and they are almost the only ones of any consequence. There is general belief that practically all of our limestones are of marine origin. Later some consideration will be given to the discussion of continental fresh or salt water limestones.

There has been considerable discussion as to the climate of regions where limestones have formed. Their presence in all latitudes plainly shows that they have not been limited to what are now the warm belts of the earth's surface. However, it is certain that the present climatic zones have not existed throughout geologic time. The wide distribution of various organisms indicating equable climate over extensive areas and the presence in the rocks of polar or near-polar regions of some plant and animal forms whose descendants now require tropical conditions give basis for the belief that in certain periods warm climates existed over the entire earth. Recognizing these situations, geologists do not hestitate to suggest that marine limestones have accumulated in warm waters. The reason for preferring such conditions are that many of the groups of animals entering largely into the composition of limestones are now limited to tropical waters and that the calcareous deposits now forming in the seas are largely confined to the warmer regions. For example, the living corals of our coral reefs can not exist in water colder than 68°F. and we are inclined to believe that the corals forming our Paleozoic coral reefs probably required similar temperatures for their growth. Coral reefs in Paleozoic limestones are known in Pennsylvania, Michigan, Sweden and many other places in latitudes far north of any existing coral reefs. Animals and plants living in cold regions extract calcium carbonate from ocean waters as has been noted by the writer near Norwegian islands north of the Arctic Circle where calcareous marine algae and shelled animals were fairly abundant, yet calcareous secreting animals and plants are much more abundant in warm waters at the present time and probably always have been.

By way of summary, therefore, it may be stated that our marine limestones in the great majority of cases have accumulated in shallow waters under tropical conditions of temperature.

PRIMARY SOURCE OF THE LIMESTONE AND DOLOMITE CONSTITUENTS

In a discussion of the origin of limestones and dolomites, it is well to account for the primary source of the elements of which they are composed so far as this can be done, although it is recognized that these rocks owe their immediate origin to secondary processes. The elements entering into these rock classes are the metals calcium and magnesium and the non-metallic elements carbon and oxygen.

Calcium. Calcium is one of the most abundant elements of the igneous rocks. It is exceeded in amount only by oxygen, silicon, aluminum and iron. It might be stated incidentally that oxygen and

silicon constitute 46.42 and 27.59 per cent respectively. Clarke* estimates that calcium constitutes 3.61 per cent of the igneous rocks and that "the average composition of the lithosphere is very nearly that of the igneous rocks alone." It is never found in nature uncombined but does enter into the composition of a very large number of minerals, especially the complex silicates which largely compose the igneous rocks. Clarke mentions "anorthite, garnet, epidote, the amphiboles, the pyroxenes, and scapolite" as igneous rock minerals rich in calcium.

Magnesium. Magnesium is also one of the more abundant metals of the known portion of the earth. Clarke estimates that it constitutes 2.09 per cent of the average composition of the igneous rocks and is exceeded in amount only by the elements oxygen, silicon, aluminum, iron, calcium, sodium, and potassium. It is an important constituent of the amphiboles, pyroxenes, micas, and olivine among the igneous rock silicate minerals and of talc, chlorite, and serpentine of the metamorphic rocks.

Carbon. A few silicate igneous rock minerals contain carbon; cancrinite is an example. The important primary source, however, is carbon dioxide which constitutes an appreciable amount of the volcanic gases and of the atmosphere. Clarke estimates that it forms .051 per cent of the average composition of the igneous rocks.

Oxygen. Oxygen is the most important and abundant element known. It constitutes 46.42 per cent of the average composition of the igneous rocks and enters into the composition of the majority of the rock-forming minerals. It forms the larger part of the water of the earth's surface and in the uncombined state constitutes about one-fifth of the atmosphere.

SOLUTION AND TRANSPORTATION OF CONSTITUENTS

Carbonation, oxidation and hydration are the active chemical changes in rocks at the surface of the earth and account for the breaking down of the complex silicates of the igneous rocks and the resultant formation of the simpler compounds—carbonates, oxides and hydrates. Carbonation is the combination of a substance with carbon dioxide; oxidation, with oxygen; hydration, with water.

Carbonation most commonly affects the silicate minerals, carbon dioxide combining with the basic elements to form carbonates and setting free the silica. Water charged with carbon dioxide acts readily on the calcium silicates forming calcium bicarbonate [$CaH_2(CO_3)_2$] which, being soluble, is readily carried in solution by ground water. Magnesium silicates are acted upon in the same way.

The sulphur contained in some of the minerals in igneous rocks, notably pyrite, by the process of oxidation forms sulphureous and sulphuric acids which in turn may react with calcium and magnesium solutions to form sulphates of calcium and magnesium. These salts also are soluble and are taken into solution by ground waters.

Further, some calcium and magnesium goes into solution in ground

*Clarke, F. W., Data of Geochemistry; p. 29, U. S. Geol. Survey, Bull. 770, 1924.

waters as chlorides, but by far the greater portion is transported as the bicarbonates.

Ground water carrying these salts in solution eventually finds its way into the streams and by these the salts are carried to the sea. Thus, the transportation of the constituents of limestones and dolomites is a chemical process in contrast to the mechanical transportation of sand and silt which form the constituents of sandstones and shales. The checking of the velocity of the stream along its course or at its mouth does not precipitate the calcium and magnesium compounds from solution as is the case with sand and silt; consequently, we must look for causes within the sea to explain the deposition of these compounds as our limestones and dolomites.

PRECIPITATION OF CALCITE AND DOLOMITE FROM SOLUTION

Certain of the soluble constituents of the ocean waters derived from the rocks of the continents remain there more or less permanently and have hence accumulated in large quantities during the millions of years since the ocean basins have been filled with water. The greater portion of the sodium which is mainly combined with chlorine has remained there and hence the oceans since the beginning have gradually become more saline. The calcium and magnesium, however, are continually being precipitated from solution and this extraction has resulted in the formation of our limestones and dolomites.

Precipitation of the calcium and magnesium carbonates from the ocean or inland waters may take place as the result of either organic or inorganic processes. Limestones owe their direct origin in most cases to the action of organic life. However, the same substances may be precipitated from solution by chemical processes in no way dependent upon organisms and some limestones have undoubtedly been so formed.

Limestones are frequently classified with reference to origin into marine and fresh water types and in this report will be so designated. This has practical importance because of the greater uniformity and wider areal distribution of the marine strata. In the following paragraphs the organic and inorganic agencies in the formation of limestone are discussed.

ORGANIC AGENCIES

A wide variety of animals and plants is concerned in the formation of limestone. These include all groups that possess the ability to extract calcium carbonate from solution and to build it into their structures as internal or external skeletons or to cause its precipitation by chemical changes consequent upon their life activities. Among animals the important groups are the mollusca (gastropods, pelecypods, cephalopods, and pteropods), brachiopods, crinoids, bryozoa, corals, and foraminifera. The important plant groups are the algae and bacteria. Limestone largely composed of the remains of the mollusca and brachiopods, is termed shell limestone, those in which the crinoids, corals, or foraminifera are abundant and easily recognizable are known as crinoidal, coralline, or foraminiferal limestones. Some limestones are named for a particularly abundant fossil, such

as the fusulina limestone, named for a genus of foraminifera that lived in great numbers during Carboniferous times in certain seas.

Clarke and Wheeler[1] have made analyses of a number of marine invertebrates possessing calcareous parts and thus capable of forming limestone by their accumulation. The following table summarizes their results.

Fossil crinoids were found in addition to contain from zero to 2.21 per cent $FeCO_3$, averaging 0.82, and from zero to 0.26 per cent $MnCO_3$, averaging 0.08.

The absence of recognizable organic remains in limestone must not be assumed as evidence of its inorganic origin. Shell and coral fragments may be reduced to fine grains by the action of waves and currents. Again, all traces of the organisms may be destroyed by secondary changes such as crystallization and dolomitization. Most of our marbles, especially the coarse-grained varieties, present no indication of fossils although there may be evidence that they probably were formed from highly fossiliferous strata.

Part of the calcium carbonate of the calcareous-secreting organisms exists in the form of calcite and part as aragonite. In some shells these minerals form alternating layers. Aragonite is less stable and after the death of the organism tends to pass into solution or change to calcite so that it is of little importance in our present limestones. Clarke and Wheeler[2] state that their analyses of the marine invertebrates and calcareous algae show that those groups with aragonite skeletons are almost completely non-magnesian.

"In what manner do plants and animals withdraw or segregate calcium carbonate from sea water? To this question there have been many answers proposed[3], but the problem is essentially physiological, and its full discussion would be inappropriate here. Some of the answers, however, were framed before the modern theory of solutions had been developed, and are therefore no longer relevant. It is not necessary to ask whether the living organisms derive their calcareous portions from the sulphate or chloride of calcium or absorb the carbonate directly, for these salts are largely ionized in sea water. It is only essential that calcium ions and carbonic ions shall be simultaneously present; then the materials for coral and shell building are at hand. The carbonic ions may be of atmospheric origin, or brought to the sea by streams, or developed by the physiological processes of marine animals, or a product of organic decay; all of these sources contribute to the one end and help to supply the material from which limestones are made. Where marine life is abundant, there also the carbonic ions abound."[4]

Foraminifera. The foraminifera, long recognized as important rock builders, are small animals that secrete calcareous skeletons of great variety in size, shape, and structure. Most of them are smaller than the head of a pin, although varieties, such as the *Nummulites* of Europe, Africa, and Asia are flat disk-like bodies ranging in size to more than an inch in diameter and are almost the only form in certain

[1]Clarke, F. W., and Wheeler, W. C., The inorganic constituents of marine invertebrates: U. S. Geol. Survey, Prof. Paper No. 102, Washington, 1917.

[2]Op. cit. p. 52

[3]See R. Brauns, Chemische Mineralogie, pp. 377-378, for a summary of this subject.

[4]Clarke, F. W., Data of Geochemistry: U. S. Geol. Survey, Bull. 770, p. 560, 1924.

Inorganic Constituents of Marine Invertebrates.

Name	Number of Analyses Averaged	SiO_2 Avge.	SiO_2 High	SiO_2 Low	$(Al,Fe)_2O_3$ Avge.	$(Al,Fe)_2O_3$ High	$(Al,Fe)_2O_3$ Low	$MgCO_3$ Avge.	$MgCO_3$ High	$MgCO_3$ Low	$CaCO_3$ Avge.	$CaCO_3$ High	$CaCO_3$ Low	$CaSO_4$ Avge.	$CaSO_4$ High	$CaSO_4$ Low	$Ca_3P_2O_8$ Avge.	$Ca_3P_2O_8$ High	$Ca_3P_2O_8$ Low
Foraminifera	5	4.93	15.33	0.03	1.87	4.94	0.09	7.43	11.08	1.79	85.77	89.76	77.02	------	------	------	Trace	Trace	0.00
Calcareous sponges	2	4.59	7.81	1.33	5.58	5.72	5.45	6.69	8.00	5.37	76.39	81.64	71.14	?	?	?	6.75	9.96	3.55
Madreporarian corals	29	0.18	1.25	0.00	0.15	0.74	0.00	0.49	1.11	0.09	99.17	99.71	97.57	0.01	0.21	0.00	Trace	Trace	0.00
Alcyonarian corals	22	1.16	18.05	0.00	0.50	5.80	0.03	11.24	15.73	0.35	82.19	98.93	52.23	2.20	5.43	Trace	2.71	13.35	Trace
Hydroids	6	0.10	0.24	0.02	0.09	0.21	0.05	0.54	1.28	0.22	98.31	99.63	96.77	0.96	1.80	0.06	Trace	Trace	Trace
Annelids	3	------	------	------	------	------	------	3.35	9.72	0.00	96.07	99.55	89.56	0.04	0.13	Trace	0.54	0.99	Trace
Crinoids (existing)	21	0.57	5.73	0.02	0.54	1.41	0.08	10.72	13.37	7.86	87.88	91.55	83.47	------	------	------	0.29	1.12	Trace
Fossil crinoids	10	6.21	29.30	0.24	1.38	2.66	0.28	3.43	20.23	0.80	88.06	96.07	67.24	------	------	------	0.02	0.20	0.00
Sea urchins	7	2.13	9.93	0.05	1.52	5.20	0.18	7.29	10.38	5.99	87.72	93.13	77.91	1.10	2.56	0.38	0.24	1.06	Trace
Star fishes	11	1.11	2.47	0.24	0.58	1.17	0.11	10.73	14.08	7.79	86.91	91.06	84.36	0.20	1.91	?	0.47	1.14	0.18
Holothurians	1	0.15	------	------	0.34	------	------	13.84	------	------	83.29	------	------	2.38	------	------	Trace	------	------
Bryozoa	9	4.84	16.71	0.18	0.87	2.41	0.12	6.13	11.08	0.63	85.19	96.90	63.29	2.36	8.47	?	0.61	2.68	Trace
Calcareous brachiopods	5	0.23	0.52	0.06	0.23	0.48	0.04	2.42	8.63	0.49	96.10	98.61	88.59	0.83	1.72	0.26	0.19	0.57	Trace
Phosphatic brachiopods	4	0.69	0.91	0.49	0.64	1.16	0.29	2.97	6.68	0.79	4.59	8.35	1.18	5.16	8.37	2.93	82.91	91.74	74.73
Pelecypods	11	0.18	0.36	0.00	0.14	0.50	0.04	0.22	1.00	0.00	99.42	99.87	98.60	------	------	------	0.04	0.40	Trace
Scaphopods and amphineurans	2	0.51	0.61	0.40	0.24	0.27	0.22	0.33	0.45	0.20	98.75	99.13	98.37	0.17	0.35	?	Trace	Trace	Trace
Gastropods	20	0.52	2.26	0.00	0.34	1.89	0.04	0.29	1.78	0.00	98.73	99.95	96.60	0.02	0.20	0.00	0.10	0.85	Trace
Cephalopods	3	0.09	0.19	0.00	0.11	0.15	0.06	2.60	6.02	0.16	97.20	99.50	93.76	------	------	------	Trace	Trace	Trace
Crustaceans (barnacles)	6	0.45	2.12	0.03	0.37	0.72	0.15	1.75	2.49	0.75	97.30	99.07	95.53	------	------	------	0.13	0.77	0.00
Crustaceans (crabs, lobsters, shrimps)	11	0.91	3.82	0.00	0.50	1.14	0.06	8.89	15.99	4.84	69.42	82.64	28.56	2.02	5.33	0.60	18.26	49.56	6.57
Calcareous algae	20	0.60	3.50	0.02	0.34	1.62	0.01	14.04	25.17	0.02	84.16	99.21	73.63	0.80	1.39	0.03	0.06	0.43	Trace

thick limestone strata. The chalk deposits of England, France, and Belgium are mainly composed of small foraminiferal shells; certain limestones of Carboniferous age in this country are constituted in great part of a genus called Fusulina; and at present foraminiferal remains in which the genus Globigerina predominates, cover almost 30 per cent of our ocean basins.

The limestones of Pennsylvania are not rich in foraminiferal remains. They have been noted, however, and recent studies of the residues of some of the limestones of the central and eastern portions of the State after the removal of the soluble carbonates by acid have shown their presence. Nevertheless they constitute an insignificant proportion of the limestone.

Sponges. Certain sponges having calcareous spicules or skeletons have contributed considerable material locally in the formation of limestones. The remains of sponges are not important in the formation of Pennsylvania limestones.

Corals. In the warm shallow marine waters coral life is abundant and coral reefs are in process of steady growth. Early in the development of life on the earth, reef-building corals had a much wider distribution than now. Some beds of limestone in Pennsylvania are composed almost entirely of coral remains. This is especially true of the Helderberg limestones which are widely distributed throughout the central part of the State and which contain unusually well preserved coral remains. Near Hollidaysburg a limestone largely composed of fossil corals was once worked and in recent years a similar limestone has been quarried in the northeast part of Altoona. These deposits are ancient coral reefs and comparable to the modern coral reefs now forming in tropical shallow ocean waters. Elsewhere in the State, coral remains are also present, although they are much less abundant in the Cambrian, Ordovician, Carboniferous, and Triassic limestones.

Hydroids. The Paleozoic limestones of Pennsylvania, especially the Helderberg series, contain many specimens of Stromatopora, a hydrocoralline member of the Hydrozoa. Heads of this form up to 10 feet in diameter have been found. The mass is composed of thin concentric layers that resemble the algae Cryptozoon described on a later page, but showing distinctive structures on closer examination.

Crinoids. Of the large group of the Echinodermata there are many calcareous varieties belonging to the cystoids, blastoids, crinoids, star fishes, and echinoids but only the crinoids constitute any considerable part of limestones. The crinoids, called sea lilies or rock lilies because of their resemblance to plants, are composed of calcareous plates that in most cases become separated in the decomposition of the organic portions of the animals. So numerous were they in some of the Paleozoic seas that limestone beds in many places are almost entirely composed of the flat hollow disks that formed their stems. They are abundant in the limestones of this State.

Bryozoa. The bryozoa, with coral-like structures of extremely great variety, are common fossils in the limestones of the State and have contributed materially in their formation. Small, branching, tree-like

varieties and flat, fan-shaped forms with numerous openings are most common.

Brachiopods. In the Paleozoic seas these bivalve shelled animals, sometimes mistaken for mollusks, lived in great numbers and variety and are the most common fossils recognized in our limestones. Their shells are in better state of preservation than most of our fossils and thus readily recognized. They are important rock builders, although it must be admitted that most of the specimens found in Pennsylvania are casts or moulds in the shales.

Mollusca. The shelled mollusca, Pelecypods (clams, etc.), Gastropods (snails, conchs, etc.), Cephalopods (squids, cuttle fish, etc.), Scaphopods, and Amphineura (chitons) have existed since the early Paleozoic in great numbers. They lived mainly in shallow water and their shells have been tossed into piles or broken by the waves of the ocean. The accumulations compacted into limestone have been found locally in every geologic period.

Other animal groups. Remains of other animal groups are found in our limestones, but except locally are insignificant parts of the rock. Among these are worms that secrete calcareous tubes in which they live, various crustaceans, mainly trilobites, and the great division of vertebrates.

Algae. The agency of plants in the formation of calcareous deposits has been minimized in the past but we are now convinced that they have been of extreme importance and in many places have contributed more to the deposition of limestone than have animals. Although a number of plants are known to possess the ability to precipitate calcium and magnesium carbonates from solution the algae and bacteria seem to be the most important.

The algae thus far investigated include both fresh and salt water forms whereas the known bacteria with this power are all marine. The fresh water calcareous-secreting algae have been studied by many botanists and geologists largely because of the economic importance of the deposits formed by them. In New York, Michigan, Indiana and to a lesser degree in other States bog marl or bog lime has long been dug or dredged from existing or extinct glacial lakes and utilized in the manufacture of Portland cement and lime, or for fertilizing the soils. The investigation of the marls of Michigan* proved conclusively that the fresh water *Chara* (Stonewort) was mainly responsible for the deposits although some of the blue-green algae likewise were agents of precipitation. The latter commonly form ellipsoidal pebbles with concentric radial arrangement. Probably other water plants are also concerned in the formation of marl but to a lesser degree.

The algae investigated precipitate the calcareous material in their stems and these plant structures have been detected throughout the marl deposits of Michigan. They have also been recognized in some of the Tertiary limestones underlying Paris.

The deposits of algal marl in Pennsylvania have received little attention as yet but are known to exist in a few places. In Centre

*Davis, C. A., Lane, A. C., Hale, D. J., Marl (Bog Lime); Geol. Surv. Mich., vol. 8, pt. 3, Lansing, 1903.

County some marl of this kind has been dug for fertilizer. The chief interest to us in this type of calcareous sediment is that it suggests a probable origin of the compact, structureless, fine-grained, fresh-water limestones of the upper Coal Measures of the western part of the State. These are mainly non-fossiliferous although some of them contain a few fresh-water shells just as do the Michigan marls.

Fresh-water algae are also present in streams and springs. The thick deposits of travertine about the Mammoth Hot Springs of Yellowstone Park owe their origin mainly to the action of algae, some of which are able to live in water near the boiling temperature. Calcareous nodules formed by the blue-green algae have been found in some of the streams of the State. Occurrences of this kind are described in the chapter on Lancaster County.

Marine calcareous algae, commonly called Nullipores, are known to be of the greatest significance in the formation of limestone. There are several kinds, foremost of which are Lithothamnium, Halimeda, Diplopora, Corallina, etc. These were long known to be prominent in the formation of coral reefs but now it seems that in many cases they have contributed even more to these structures than the corals.[1] The Triassic dolomites of the Tyrolean Alps are said to have been formed mainly through the agency of algae. In the Lower Cambrian of this State we find numerous examples of calcareous algae.

One abundant variety of calcareous algae is *Cryptozoon proliferum*. Large to small specimens of this plant form a large part of the strata of the Conococheague (Allentown) limestone in many places in the Bethlehem region. It is not improbable that other forms of calcareous algae whose structures were less favorable for preservation may likewise have contributed to the formation of our Paleozoic limestones.

As shown in the analyses of Clarke and Wheeler on a preceeding page, the structures of the marine calcareous algae are highly magnesian and this may largely account for the abundance of dolomite or rich magnesian limestone of the Cambrian and Ordovician strata of the State.

Bacteria. In recent years considerable information has been obtained concerning the work of bacteria in the precipitation of calcium carbonate from the ocean waters, and it is now generally believed that many of our non-fossiliferous limestones owe their origin to bacterial processes.

In some of the muds near the Bahama Islands and the Florida Keys, Drew[2] found 160,000,000 specimens of *Bacterium calcis* (later determined to be *Pseudomonas calcis*[3]) per centimeter and concluded that the fine calcareous deposits of those regions had been formed largely through their activities. One method described by Kellerman and Smith is the formation of ammonia by the decomposition of proteids or by the reduction of nitrates to nitrites and to ammonia and the further formation of ammonia carbonate by reaction with carbon

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[1] Howe, M. A., The building of coral reefs: Science, new ser. vol. 35, pp. 837-842, 1912.

[2] Drew, G. H., On the precipitation of calcium carbonate in the sea by marine bacteria: Carnegie Inst. of Washington, Pub. 182, pp. 7-45, 1914.

[3] Kellerman, K. F. and Smith, N. R., Bacterial precipitation of calcium carbonate: Jour. Wash. Acad. Sci., vol. 4, pp. 400-402, 1914.

dioxide produced by plants or animals. In the presence of $CaSO_4$ or its ionized constituents, the following reaction would take place:

$$CaSO_4 + (NH_4)_2CO_3 = CaCO_3 + (NH_4)_2SO_4$$

Vaughan[1] reports that these denitrifying bacteria precipitate the calcium carbonate largely as aragonite and that it frequently tends to form small balls or spherules that by accretion become oolite grains. He believes that "all marine oolites, originally composed of calcium carbonate, of whatever geologic age, may confidently be attributed to this process."

In recent years some important work has been done in the Bahama Islands, especially on Andros Island and the great bank of calcareous mud covered by shallow water and extending westward from the island and covering about 7000 miles. These investigations are of interest as it is believed by many geologists that conditions there are similar to those that resulted in the formation of the unfossiliferous Paleozoic limestones of Pennsylvania and other sections in the Appalachian Province. Although the investigations have not been completed, enough has been determined to indicate that the calcareous muds have not been formed by precipitation in the open ocean by bacteria of the kind described by Drew. Dr. R. M. Field,[2] director of the expeditions, describes the present status of the problem as follows:

"As to the organisms which may be responsible for the precipitation of calcium carbonate, Doctor Bavendamm reports as follows:

"'Apart from the types which Drew and others have erroneously termed 'calcium bacteria,' going so far as to attach special names to them, there were found in many places numerous ureabacteria which to this day have escaped observation. These bacteria, like the denitrifying forms observed by Drew, are able to precipitate calcium carbonate under certain conditions. Also the strictly anaerobic, sulphate-reducing bacteria, which are probably important in the process of calcium carbonate precipitation, were found to exist everywhere. The presence of very active cellulose and hemicellulose-destroying bacteria attracted special attention. These organisms were notable for their ability to dissolve agar-agar made from brown and red algae, and are so abundant that they are believed to be not only responsible for the decomposition of the abundant organic matter in the mangrove swamps but together with other bacteria they might well aid in the precipitation of $CaCO_3$.'

"As the result of their recent experiments, Doctor Waksman and Doctor Bavendamm do not agree with the former ideas of Doctor Lipman (1929) that the great area of calcium carbonate mud in the Bahamas is the result of strictly physico-chemical processes, but they believe that it is rather the result of microbiological processes. Their conclusions have been reached not only from the inspection of crude and pure cultures of the various organisms in the laboratory, but also from the bacteriological-hydrobiological viewpoint. It is interesting to note, however, that the most favorable locations for the bacterial

[1] Vaughan, T. W., Preliminary remarks on the geology of the Bahamas, with special reference to the origin of the Bahaman and Floridian oolites: Carnegie Inst. of Washington, Pub. 182, p. 47-54, 1914.

[2] Field, R. M. and collaborators, Geology of the Bahamas: Bull. Geol. Soc. of America, vol. 42, pp. 759-784, 1931.

precipitation of calcium carbonate are not in the marine muds, but in the mangrove swamps, lakes and brackish-water areas on Andros Island. It would appear therefore that an appreciable quantity of the fine-grained calcium carbonate muds in the Bahamas, no matter what their present location, might have originated under fresh or brackish-water conditions."

Before the investigation of Drew, Vaughan, Kellerman, and Smith, Daly* had formulated an hypothesis to the effect that in the pre-Cambrian and early Paleozoic seas the organic matter, both plant and animal, collected on the ocean bottoms and there decomposed, forming ammonium carbonate that reacted with the calcium and magnesium solutions to form precipitates of calcite and dolomite. Until the appearance of the fishes there were few scavengers living near the bottom and feeding on the decaying organisms there accumulating so that this agency was responsible for a "large part, if not all, of the pre-Cambrian limestones and dolomites, but as well, the limestones and dolomites of the early Paleozoic formations. This precipitation grew slower in proportion to the development of the fishes and other efficient bottom scavengers. When the scavenging system became well established calcium salts could, for the first time, accumulate in the ocean water in excess of the needs of the lime-secreting organisms. Thereafter the marine limestones have been largely formed from the debris of the hard parts of animals and plants."

The pre-Devonian limestones of the State are markedly deficient in fossils. Whether they owe their origin mainly or entirely to the action of bacteria or to the somewhat similar process discussed by Daly cannot be definitely stated at present. The limestones possess the characteristics of normal chemical precipitates but in the opinion of the writer are probably attributable to organic agencies.

INORGANIC AGENCIES

In the past many if not most of the non-fossiliferous limestones were considered purely inorganic in origin, but now are referred to some of the organic processes described above. Locally there are deposits of calcium carbonate undoubtedly formed in several different ways without the aid of organisms. However, in the aggregate they are of little economic importance.

When bodies of water disappear by evaporation, probably in every instance, deposits of calcium carbonate are formed, because of its almost universal presence in lake and ocean waters. In regions where the rainfall is deficient and evaporation excessive, deposits of limestone have been observed to form in river beds but only in limestone regions where the waters are highly charged with calcium carbonate. Near waterfalls, calcareous precipitation is apt to form by evaporation of the spray.

Many hot springs and some cold ones heavily charged with calcium carbonate form deposits of tufa or travertine near their vents. Algae are, in some cases, responsible for the precipitation but liberation of carbon dioxide, evaporation, or cooling of the water will cause deposition.

The stalactites and stalagmites of caves are produced by evapora-

*Daly, R. A., First calcareous fossils and the evolution of the limestones; Bull. Geol. Soc. Amer., vol. 20, pp. 153-170, 1909. The limeless ocean of pre-Cambrian time: Amer. Jour. Sci., 4th ser., vol. 23, pp. 93-115, 1907.

tion and loss of the carbon dioxide responsible for holding the calcium carbonate in solution. The beautifully colored cave onyx extensively used as an interior decorative stone originates in this way.

The precipitation of calcium carbonate from ocean water at several places, especially near the mouths of rivers, has been described, and explained by purely inorganic processes involving chemical changes. Most of these instances are not sufficiently supported by careful observations to warrant their acceptance. Calcite-secreting bacteria suggest another explanation.

ORIGIN OF DOLOMITE

Scarcely another question of geologic inquiry has received as much attention as that concerning the origin of dolomite. French, German, Belgian, English, and American geologists have attacked the problem and scores of monographs based on observations and experiments have been written in support of one theory or another but there still remain many divergent views. A summary of the literature is impracticable in this place but the problem is of such great economic importance to the users of limestone in Pennsylvania that it cannot be ignored. Certain of our limestones are sought because of their high magnesian content and others are rejected on account of it. In some sections high and low magnesian limestones are so mixed that the stone cannot be utilized for purposes requiring the one but not the other.

There is no sharp line between dolomite and limestone. Careful study of magnesian limestones seems to indicate that nearly all the magnesium present exists as part of dolomite ($(CaMg)(CO_3)_2$) molecules and a true dolomite rock is one in which all the calcium exists in the same form. In most cases both dolomite and calcite crystals compose the rock and seldom is either one entirely absent, although in general, rocks low in dolomite crystals are more abundant than the others. Some of our limestones may contain magnesium as uncombined $MgCO_3$ but this is not common. Analyses showing more than 45.61 per cent of $MgCO_3$, the theoretical percentage of dolomite, are rare although there are some examples of rocks containing over 50 per cent $MgCO_3$.

The theories that have been formulated present many different viewpoints and lead to the belief that dolomite can be produced under several conditions and in all probability has been produced in nature in different ways. Dolomite is reported to have been prepared synthetically in the laboratory by many investigators* but we cannot be certain that any of the processes employed have been duplicated in nature.

Under unusual conditions normal dolomite may have been formed as a primary chemical precipitate in shallow ocean water but it seems probable that most of our highly magnesian limestones owe their origin to secondary changes.

The analyses of the skeletons of various marine invertebrates and calcareous algae, given on a preceding page, show that many of the organic calcareous deposits accumulating in the seas contain considerable amounts of magnesium carbonate, especially the foraminifera,

*Clarke, F. W., Data of Geochemistry: U. S. Geol. Survey, Bull. 770, pp. 565-580, Washington, 1924. Van Tuyl, F. M.: Origin of dolomite; Iowa, Geol. Surv. vol. 25, pp. 251-421, Des Moines, 1916.

alcyonarians, echinoderms (crinoids, sea urchins, starfishes, and holothurians), crustaceans, and coralline algae. Clarke and Wheeler give an analysis of a species of algae, *Goniolithon strictum*, from Soldiers Key, Florida, which contained 25.17 per cent $MgCO_3$. In their studies they found that the forms living in warm waters had a higher percentage of magnesium, a condition which seems to be general in the different groups and may indicate that our dolomitic limestones were largely formed in the warm waters of the Paleozoic seas.

Those organisms that have aragonite as part of their skeletons form deposits that favor dolomitization because that mineral is more soluble than calcite.

Unless organisms in the past had the ability to extract from ocean water a larger amount of magnesian salts than is possessed by forms living now, it is evident that secondary action has been involved in the formation of our magnesian limestones, inasmuch as numerous strata contain more than 40 per cent $MgCO_3$. The secondary change may have been enrichment either by the removal of $CaCO_3$ or by replacement. In all probability both processes have taken place and in most cases it is difficult to say which method has prevailed.

A disputed point concerns the time when and place where the leaching of the $CaCO_3$, or its replacement, occurred. Geologists seem to favor the belief in the change having been effected mainly on the ocean bottom when the limestone existed in the unconsolidated condition as ooze or loose shells. Magnesium exists in ocean water in much larger quantity than calcium, averaging about 3.68 per cent of the salts contained in solution. By the action of decaying organic matter in warm, shallow waters the solution of $CaCO_3$ and also the substitution of magnesium for calcium are believed to have gone forward rapidly. The effect of decaying organisms is shown by the selective replacement of fossil shells by dolomite in some limestones in which the matrix remains calcite.

In most cases the action of sea water probably ceased rather uniformly at shallow depths in the deposits and the variation in composition in individual beds is not marked. In places, however, one finds a bed changing in a short distance laterally from a dolomite to a low magnesian limestone. Conditions of this kind are interpreted to mean a continuation of the alteration, after the deposition of overlying deposits, due to some physical characters that gave ready access to the magnesian waters in certain places but not everywhere.

In some limestone quarries of this State, dolomitization has taken place on a considerable scale and the rock varies materially in composition even though the beds are continuous.

In the shells of organisms magnesium carbonate and calcium carbonate seem to exist as separate molecules and there is still no direct evidence of the way in which the double molecule of dolomite is formed although theoretical explanations have been offered.

We accept the view of dolomitization at the time of formation of the limestone as the most plausible explanation for most of our magnesian limestone but are still without definite evidence to account for the extreme and sharp variations that prevail in the alternating strata of the Cambrian and Ordovician rocks of this State, as described on later pages. We can only suggest changes in the density of the ocean water, changes in temperature and pressure, and changes in the character of

the organisms forming the deposits as the more probable causes. As oolites, cross bedding, intraformational conglomerate, ripple marks, sun cracks, and numerous shale laminae are characteristic of these strata, we are warranted in concluding that the water was shallow over wide expanses, thus facilitating rapid and frequent changes, such as suggested.

We cannot escape the conviction that dolomitization may have occurred in later periods as well, even after consolidation of the limestones and their uplift from beneath the ocean, by ground water circulating through the rocks. These effects, however, are subordinate to the ones described above. Limestones have been found in which the magnesian content increases with proximity to shattered zones and cracks or joints through which the ground water passes readily. In these cases the cause has been dolomitic enrichment due to the removal of the more soluble calcite.

In general the circulating ground water accomplishes little in the replacement of limestone by dolomite. Yet it must be remembered that dolomite is a gangue mineral in certain ore deposits, proving that it is carried in solution by ground water and there is thus the possibility of local replacement of $CaCO_3$ by $MgCO_3$ by this agency.

ORIGIN OF MARBLE

Marble is a metamorphic, compact variety of limestone or dolomite and differs from the original rock only in the granular, more coarsely crystalline character of the particles composing it. There is no distinct line of separation between limestone and marble but in general those calcareous stones that will take a high polish are called marble. This character depends upon the compactness of the stone and the crystallinity of the particles. The separate grains which break along cleavage planes may vary from microscopic size to crystals several inches in diameter. Marbles may be designated as calcareous, magnesian, or dolomitic depending upon the amount of magnesia present.

By experiment it has been found that pressure and heat in the presence of moisture are the effective metamorphic agents in the formation of marble. The intrusion of limestone beds by molten igneous material will change the limestone to marble for a short distance from the contact. This is called contact metamorphism and is of local importance only. The extensive areas of marble are due to pressure and heat caused by folding or compression of the earth's strata. This is designated regional metamorphism. In general those strata that have been subjected to the greatest stresses are most coarsely crystalline, although the composition of the rock, the thickness of overlying rock, the quantity of moisture present, and possibly other factors may have their effect. This is shown to good advantage in the limestones and marbles of this State where the pre-Cambrian calcareous strata have undergone intense deformation numerous times and have been converted into coarsely crystalline marbles. The Cambrian and Ordovician limestones have twice been folded and faulted and in many places have been changed into fine-grained marbles, whereas the later limestones of Carboniferous age have been subjected to a single period of mountain building by compression and are in few places sufficiently crystalline to justify their designation as marble.

As described under the topic of Chemical and Mineralogical Compo-

sition, marble formed from impure limestone contains a wide variety of minerals, the most common of which are graphite, tremolite, and garnet.

FRESH WATER CALCAREOUS MARL AND LIMESTONES

Calcareous deposits formed in fresh water are seldom extensive and consequently economically of only local importance. There are some localities, however, in Michigan where fresh-water calcareous marls are sufficiently extensive to have justified the erection of Portland cement mills for their utilization and in other places they have been dug for fertilizers and for lime burning. Also some fresh water limestones associated with the coals of the western portions of the State are of considerable value.

In Pennsylvania there are three different types of fresh water calcareous deposits: Fresh water marl of the glaciated regions, fresh water marl of the non-glaciated regions, and Carboniferous fresh water limestones.

Fresh water marl of the glaciated regions. Both northeastern and northwestern Pennsylvania were covered by the extensive ice sheets of the Glacial Period. On their retreat by melting, numerous swamps, ponds, and lakes were left as the result of glacial gouging in part, but mainly because of deposition of debris along the stream courses forming dams. In many of these small bodies of fresh water there has been a profuse growth of algae of different kinds, but particularly *Chara,* that have the ability to extract calcium carbonate from the water and precipitate it as encrustations about the plant stems. On the death of the plants, the stems decompose leaving the calcareous deposit. The origin and characteristics of these deposits have been well described in many reports but particularly well in Vol. VIII, Part III of the Geological Survey of Michigan. Similar deposits have been investigated in Michigan, Indiana, New York, and elsewhere.

In Pennsylvania these calcareous deposits of the glaciated regions have not as yet received much attention and none at all by the writer. It is not improbable that some may be of local importance. The most extensive deposit of this kind known in Pennsylvania is that near Conneaut Lake in Crawford County described in the chapter on that county.

Fresh water marl of the non-glaciated regions. The fresh water marls of the non-glaciated sections of Pennsylvania have been studied by J. B. R. Dickey and a brief report (Mimeog. Bull. 76) published by this Survey. The following paragraphs are abstracted from this report.

"On account of the popularity of marl among farmers it seems opportune to call attention to the rather frequent occurrence of marl beds in the limestone regions of Pennsylvania. While most of the deposits are too small for commercial development they could be utilized to excellent advantage as local sources of agricultural lime without the necessity for any expensive equipment, fuel for burning or power for grinding. Many similar beds are being worked by farmers in Maryland, West Virginia and Virginia and are supplying agricultural lime locally at very small expense.

"*Chemical Composition.* The marl herein discussed consists of

calcium carbonate, small percentages of magnesium carbonate, and varying amounts of earthy and organic impurities which have been mixed with it during formation and subsequent reworking. The total carbonate frequently exceeds 90 per cent but in some reworked beds does not amount to more than 50 or 60 per cent. The average carbonate content on an air dry basis is between 80 and 90 per cent. The percentage of magnesium carbonate seems always to be low, ranging from 0.5 to 2 per cent.

"*Physical Character.* This marl seems to differ from that in the ponds and marshes of the glaciated regions in the manner of its formation. The latter no doubt owes its origin to the action of algal forms of plant life and frequently occurs in places remote from any limestone formations. The marl discussed in this paper, on the contrary, is always associated with limestone or at least found along streams rising from limestone springs. While the texture commonly is very fine, like the glacial marl, it may be more or less granular. Occasionally the marl forms concretions around some small object. Short, hollow tubes of marl occur, as if the mineral had been deposited around a stick or grass blade which had subsequently rotted out. Unlike the glacial marl which is generally too soft to drive upon after the surface soil is removed, the limestone marl is generally hard and dry enough to support the weight of horses. This marl not infrequently has consolidated or become cemented together locally, into rough, whitish, horizontal slabs or concretions varying in size from a pebble up to large irregular boulders. This is most common where the marl is exposed. In many places where exposed, however, consolidation has not taken place.

"*Origin.* A plausible theory for the formation of this marl is that the water from the large limestone springs, near which it invariably occurs, emerged heavily charged with carbon dioxide and calcium carbonate, much of it in the form of bicarbonate. On exposure to the air much of the carbon dioxide passed off as a gas. The water, having lost its carbon dioxide, could no longer carry so much calcium in solution and therefore precipitated it.

"This method of formation is well illustrated by two deposits in the form of benches, one near Hancock, Maryland, and the other in Lawrence County, Pennsylvania. At the Maryland locality a small spring emerges from the limestone formation about 20 feet above stream level. A terrace of marl has been built out below the spring. As the deposit increased in size, the water from the spring apparently poured over all sides of it and continued to deposit marl until a terrace 100 feet or more in length was built. The deposit at Hancock has been dug into in development work so that the layers one above and extending beyond the other are plainly visible. The marl is more or less consolidated or crusted. Many of these layers show the impression of leaves, etc., over which the marl was deposited.

"The deposit in Lawrence County is beneath a spring which emerges about 10 feet above the level of a stream. It is interesting, because it is one of the few deposits discovered west of the Allegheny Mountains and further because the marl instead of being white is reddish brown in color, doubtless due to iron impurities. It is not as high in carbonate as the average, an analysis showing only about 65

per cent. Mixed with the loose brown marl are occasional rough, irregular, chunks of a very hard, fine-grained, brownish limestone testing about 95 per cent carbonate and differing markedly from the rather soft, porous, coarse concretions found elsewhere.

"Other deposits of marl occur as broad areas, such as those developed commercially in West Virginia. Some of these are slightly depressed, giving the impression that deposition took place in a shallow lake or marsh. In these cases evaporation and concentration of the lime-impregnated waters may have caused the precipitation. Frequently deposits along a good-sized stream may be traced to a small spring coming in from the side higher up. There is generally a purer deposit close to the spring. Small pockets of marl sometimes occur along drainage lines quite high up on hillsides and in some cases the spring which formed a deposit has found another outlet or ceased to flow. The shells of land snails are often present in such numbers around these marl deposits as to lead to the popular but erroneous impression that the marl was due to the accumulation of shells.

"*Where found.* As most commonly found, the marl occupies flat areas or small bottoms along streams. In such situations it is generally covered by 6 to 12 inches of dark brown or black surface soil. Sometimes this overlying material is somewhat mucky but more often it consists largely of fine mineral matter washed in and deposited, no doubt mixed with the insoluble portions of the original marl. Occasionally the surface covering is so thin that the ash-colored marl is turned up in plowing. The covering is entirely lacking in some places, leaving the granular or ashy marl exposed. Unless the water table is quite high, the soil overlying the marl is generally very droughty, due to the rapidity with which the water drains away through the marl. On account of the good drainage and consequent early production of crops, marl beds frequently are favorite locations for truck gardens.

"As may be expected, marl deposits vary widely in extent and depth. At Shooks Mill, 1½ miles northwest of Greencastle, a deposit at least 20 feet deep is exposed where the stream has cut through it. Generally, however, the depth of deposits is not over 5 or 10 feet, frequently less. In some cases the marl may occupy rather extensive flats and may extend continuously or intermittently along streams for several miles, a part of it at least being eroded from the original location and redeposited. These broad deposits may have been built up by successive layers.

"The marl here described always occurs along streams rising from limestone formations and is generally found close to their source. It may occur in pockets, narrow bottoms, or broad areas either low-lying or well above the present level of streams. On account of the soil covering it is generally noticed in stream banks and gullies or in the gray or ashy white material turned up in plowing or in digging ditches or post holes. The rough, white or yellow-stained concretions above referred to may lead to its discovery, though these may be carried down stream some distance from the parent material."

Some calcareous concretions of algal origin are described in the chapter on Lancaster County.

Carboniferous fresh water limestones. While the coals of central and western Pennsylvania were forming there were intervals when clear

water extended over large areas and in these basins calcareous deposits were laid down. At times the waters were saline and connected with the sea, as shown by the presence of marine fossils which are particularly abundant in the Vanport, Brush Creek, Pine Creek, Woods Run, and Ames limestones. In most cases, however, it seems that the waters of these basins were shut off from the sea by land barriers, probably of low relief, and consequently were fresh. It has been believed by some that the fresh water Coal Measures limestones were formed by chemical precipitation of calcium carbonate inasmuch as many of them contain no recognizable organic remains. It seems to the writer much more probable that these limestones owe their origin to a process similar to that now taking place in the small lakes of some of our glaciated regions. The algae of that period may have belonged to different species and varieties than those now living, but possessed the same ability while growing to extract calcium carbonate from the fresh waters. The plant remains have disappeared and the fossils which are found in some of these limestones are animals belonging principally to the mollusca and ostracod groups. The latter appear to have been a small factor in the formation of the limestones.

The fresh water limestones are generally soft, fairly high in argillaceous matter, low in magnesia, and are compact and break with prominent conchoidal fractures. They have been quarried in many places as described in later pages, but no important limestone industry is dependent upon this type of stone.

LIMESTONES OF MECHANICAL ORIGIN

A variety of limestone of limited occurrence is of mechanical origin and composed of cemented fragments of pre-existing limestones. As mentioned on a previous page, it is unusual for pebbles or angular fragments of limestone to be transported by streams without being ground to a powder by abrasion in transit or dissolved. Nevertheless, there are instances where this has actually happened and there has been an accumulation of limestone pebbles and boulders of considerable thickness but of local areal distribution. Generally quartz pebbles are intermingled or the cementing material may be siliceous, argillaceous, or ferruginous, but in the case of the Potomac marble of the Triassic, sparingly developed in Adams, Berks, Bucks, Lancaster, Northampton, and York counties, the pebbles as well as the cement are fairly pure calcareous or dolomitic matter with only enough iron to give a red color.

Rocks of this kind are either conglomerates or breccias, depending upon whether the particles are rounded or angular. The conditions that give rise to deposits of this kind are not well understood, but it appears probable that they developed under arid climates.

CHAPTER IV

WEATHERING OF LIMESTONE

The means by which limestones weather are of two sorts, those that produce physical disintegration without chemical change and those that cause chemical reactions. The latter result in decomposition which in most cases also involves disintegration. The two classes are grouped as follows.

Weathering by physical disintegration	Weathering by chemical decomposition
Corrasion and Abrasion	Solution
Frost Action	Oxidation of accessory minerals
Changes in temperature without freezing	Discoloration
Plants and Animals	Plants and Animals
	Efflorescence

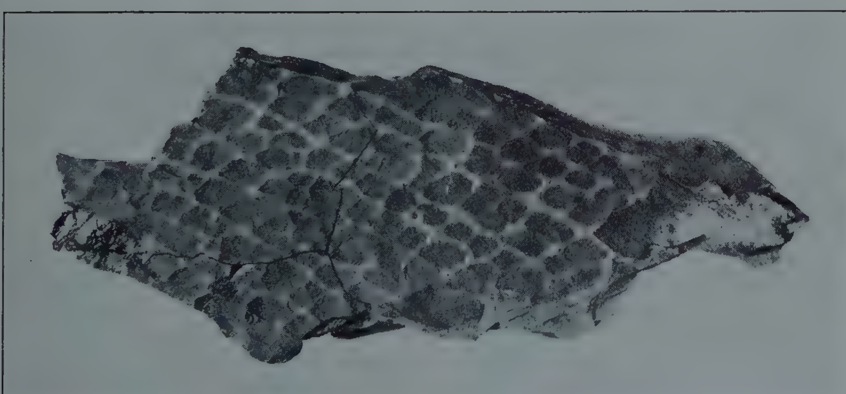
CORRASION AND ABRASION

The mechanical wear of rocks by collision of particles carried by currents of water such as streams and waves is called corrasion, and when carried by wind is called abrasion. Likewise the wear of the particles carried whether by wind or water is commonly referred to as abrasion or attrition. Limestones are considerably softer than most other rocks and hence when subjected to corrasive or abrasive action are worn away with considerable ease. Quartz sand is the most common agent of wear either by streams or by wind and tends to cut rapidly when striking the softer limestones. In Pennsylvania one rarely sees the results of limestone wear by wind action but in arid regions it is prominent. The corrasive effect on limestones in the State is also seldom noted as it is rather effectively masked by the results of the more active process of solution. However, considerable limestone must be worn away by corrasion where swift streams carry sand and pebbles over outcropping ledges of limestone. The fact that limestone pebbles are very rare in the various conglomerates of the Appalachian region even though limestones are common indicates that the fragments of limestone which must occasionally have reached streams were ground to a powder before reaching the place of permanent deposition. Sometimes one sees in the conglomerates either some pebbles of rotten limestone or cavities from which they have been dissolved, but such occurrences are unusual. On the other hand, black flint pebbles derived from the small lenses and segregations in the limestones are not uncommon features of some of the conglomerates. It might be mentioned, however, that under exceptional conditions limestone conglomerates and breccias do form, as evidenced by the Potomac marble of the Triassic which is described on later pages of this volume.

CHANGES IN TEMPERATURE

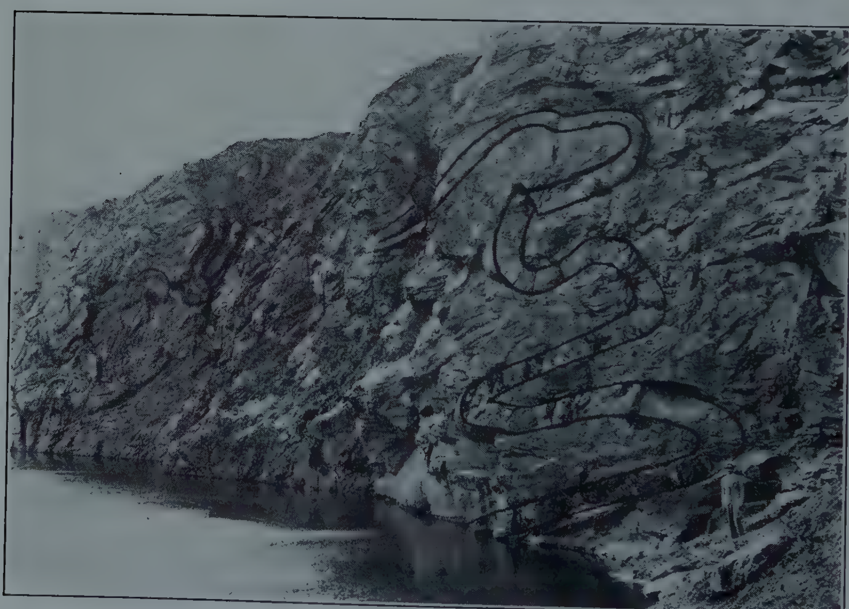
Frost action. All stones that possess porosity and hence have the ability to absorb moisture will suffer by frost action if exposed to moisture and later subjected to freezing conditions. As discussed under the topic of Porosity and Absorption on a previous page, limestones are much less porous than many other kinds of rocks and hence are less liable to disintegration by the expansive action that takes place

A. Sun-cracked Helderberg limestone breaking into polygonal blocks. One-half mile northwest of Blain, Perry County.



B. Sun-cracked shaly limestone, one mile north of Waterside, Bedford County.

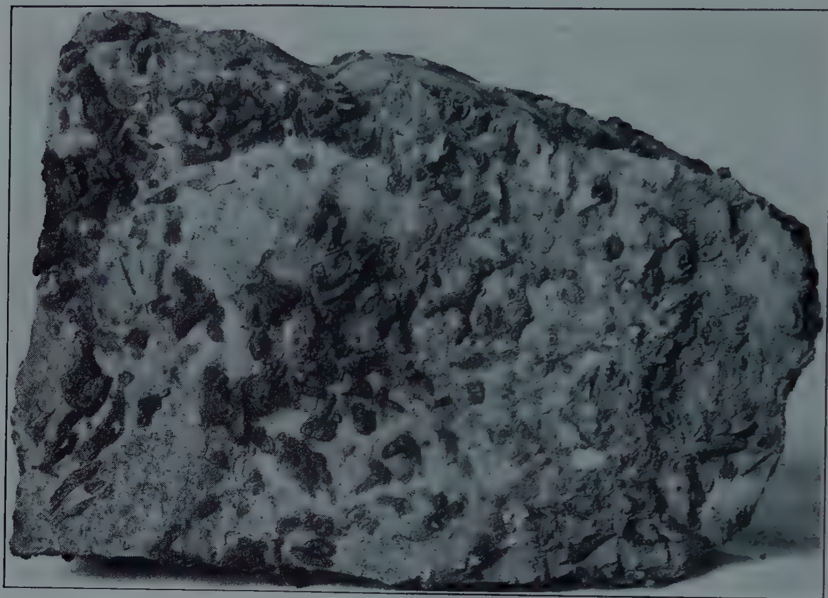
A. Contorted Beekmantown limestone in abandoned quarry ¼ mile southeast of Northampton, Northampton County.



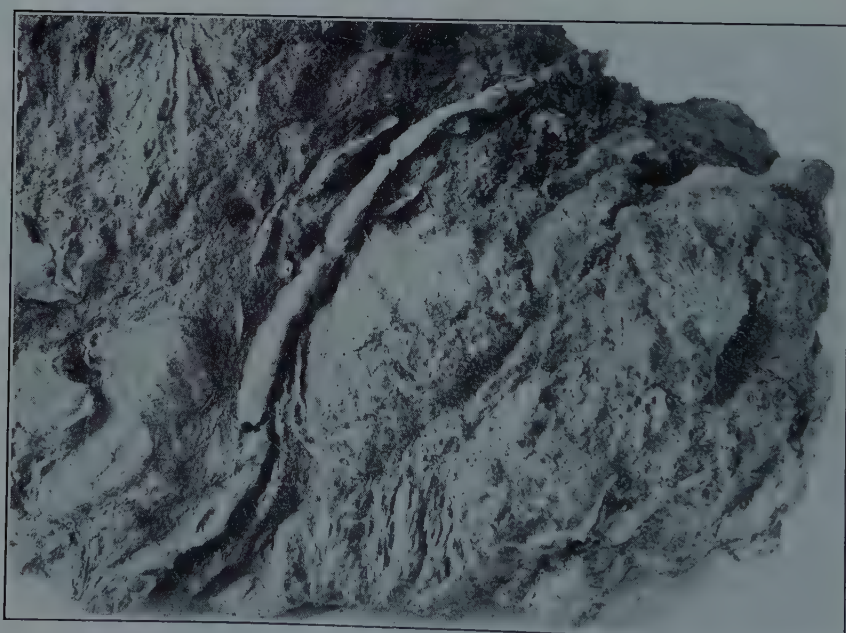
B. Another view in same quarry.

A. Symmetrical anticlinal fold in Conococheague (Allentown) limestone. Bethlehem, Northampton County. Two parallel faults are noted at right and solution pockets filled with soil at top.

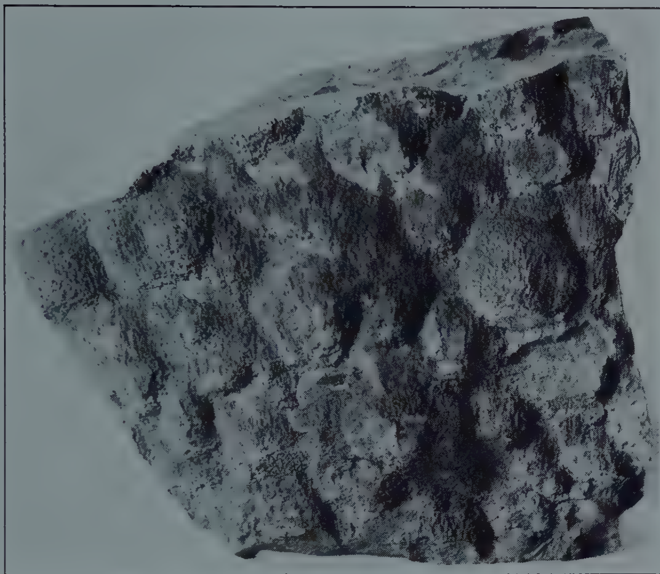
B. Bed of dolomite with low magnesian strata on either side. The dolomite bed becoming relatively plastic during folding has been constricted at fairly equal intervals.



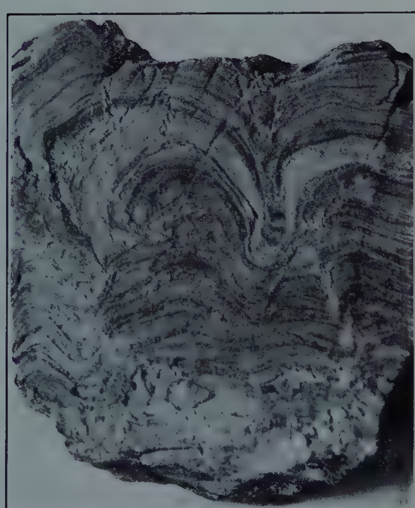
A. Bryozoa on weathered Helderberg limestone, Northumberland County.



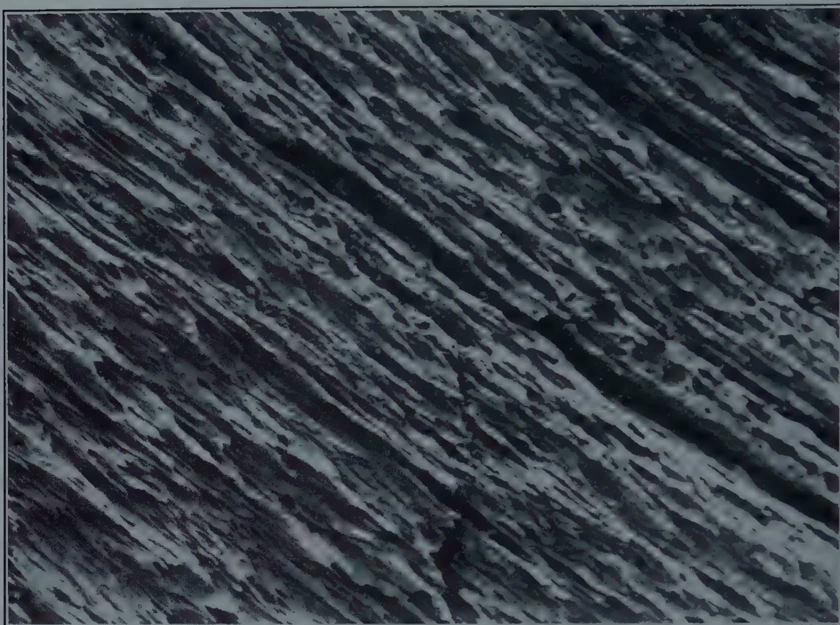
B. Corals in Ordovician limestone, Cumberland County.



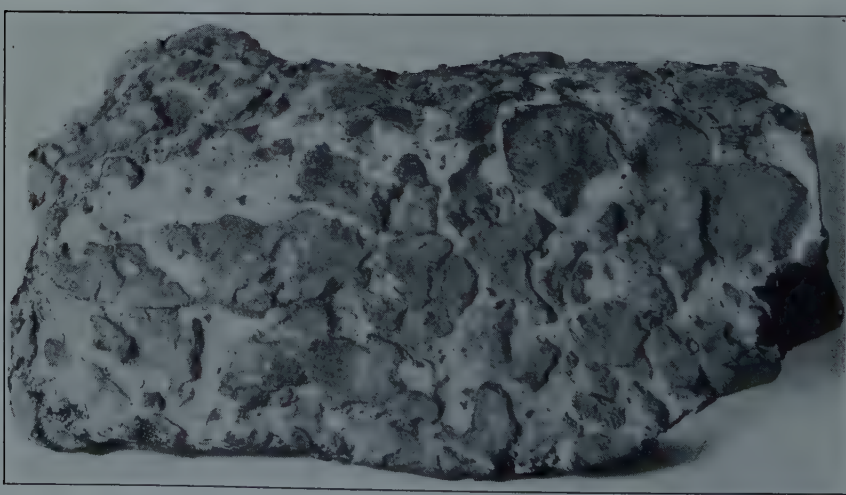
A. Top view of *Cryptozoon proliferum*.



B. and C. Side views of *Cryptozoon proliferum*, Conococheague (Allentown) limestone, Bethlehem, Northampton County.

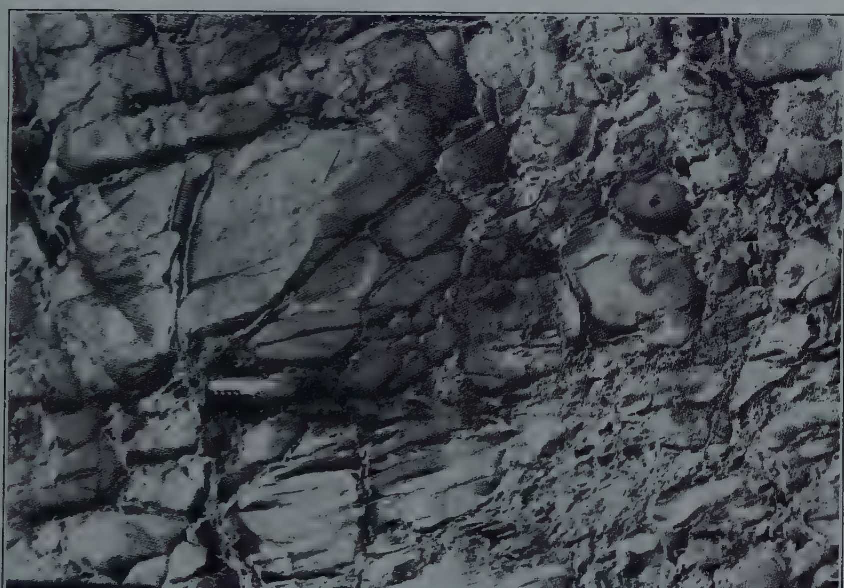


A. Beekmantown limestone, 2 miles southeast of Kutztown, Berks County. Freshly broken stone appears to have a practically homogeneous texture, whereas weathering reveals fine layers and lenses of variable composition.



B. Beekmantown limestone, Reading, Berks County. Weathered surface shows conglomerate character of rock which is not apparent on freshly broken surface.

A. Beekmantown limestone at zinc mine, Friedensville, Lehigh County. Beds standing vertical. Ore was developed along bedding planes where some layers were dissolved and ore substituted.



B. Shattered character of limestone and quartz veins at Friedensville. Calamine ore was developed in cracks in a similar manner.

A. Looking east toward incline hoists.

B. Looking west in pit half a mile long and 250 feet deep.

Two views of Cornwall iron mines, showing iron ore body formed by the replacement of limestone.

when absorbed water freezes. The writer has observed comparatively little damage resulting from frost action in the better limestones in Pennsylvania except where the rocks had already been made porous by differential solution. Limestone buildings more than 100 years old show little damage done by frost action.

Limestone used in foundations either as rubble or as aggregate in concrete is subject to moisture, and where subjected to frequent freezing and thawing may be seriously disrupted.

Kessler and Sligh* describe their freezing tests of 65 limestone samples "which were chosen as well as possible to represent the various producing districts." The specimens were immersed in water at about 20°C for 30 minutes which was thought would produce about the saturation that would result in a stone wall exposed to an ordinary rain. They were then put in a freezing chamber with a temperature of about —14°C. The specimens were thawed in tap water, the temperature of which varied from 15° to 20°C.

"The specimens were frequently examined and graded by an arbitrary system in which eight stages were recognized. The first of these was called the 'a' condition, which showed no effects of frost action, and the last the 'h' condition, at which the specimen was practically destroyed." (pp. 535-536).

"Usually three specimens of each sample were so tested, but in some cases a larger number was used. It frequently happened that specimens from the same sample showed a large difference in resistance to frost action, or in some cases one part of a specimen would disintegrate readily, the remaining part holding out in a sound condition for several hundred freezings. In computing the following summary of results the average number of freezings required to disintegrate all the specimens of a certain sample to the 'h' condition was considered as the 'resistance number' of that sample:

1.6 per cent of samples failed in less than 100 freezings.
11.0 per cent of samples failed in less than 200 freezings.
19.0 per cent of samples failed in less than 300 freezings.
25.0 per cent of samples failed in less than 400 freezings.
30.0 per cent of samples failed in less than 500 freezings.
33.0 per cent of samples failed in less than 600 freezings.
35.0 per cent of samples failed in less than 700 freezings.
41.0 per cent of samples failed in less than 800 freezings.
44.0 per cent of samples failed in less than 900 freezings.

"The number of samples which required more than 1,000 freezings to produce the 'h' condition was found to be 38 per cent of the total."

In general there was a definite relation between the porosity, absorption, and compressive strength as compared with the ease of disintegration. Those that disintegrated in less than 100 freezings had a porosity of 18½ per cent, absorption (by volume) of 14½ per cent, and compressive strength of 3500 pounds per square inch, whereas those that disintegrated between 800 and 900 freezings had a porosity of 14 per cent, absorption of 11 per cent, and compressive strength of 13,000 pounds per square inch.

*Kessler, D. W. and Sligh, W. H., U. S. Bureau of Standards, Tech. paper 349, vol. 21, pp. 497-590, 1927, Washington.

The authors estimated that their experiments were duplicated under natural conditions in the vicinity of Washington about 4 times each winter. This means that 38 per cent of the limestones would last 250 years or more. Some of them were not disintegrated after 2900 freezings, giving them a life of over 700 years. It is difficult to say how often in Pennsylvania we have during the winter freezing weather following rain without sufficient intervals of time for the stone to dry out. It does not seem to the author that in the ordinary winter season this condition occurs more than 5 or 6 times. The limestones of the State that have been used for buildings may well be expected to show little disintegration in less than 250 to 300 years.

"About 50 years ago Professor Julien made a rather extensive study of stone weathering on buildings in New York City. In his report he concluded that the durability of limestone in that city varied from 20 to 40 years. In the light of present observations this limit appears to be much too low, and it seems probable that his studies were based on inferior materials. However, under certain severe conditions which sometimes arise, almost any kind of masonry may disintegrate within a few years. In estimating the weathering qualities, one should discriminate between such local conditions and those which are general in their action." (Op. cit., p. 538)

"Probably the worst condition in buildings occurs when snow is lying on the coping, cornice, etc., and this thaws slightly in the middle of the day, which keeps those parts of the masonry fairly well soaked until freezing temperatures are again reached. Also, the lower courses of masonry are kept in a damp condition due to moisture rising through the stone by capillarity. Other parts of buildings are less subject to soaking, and while the condition of saturation in the tests may be comparable with that of the more exposed part of the masonry it would probably be overdrawn for other parts. However, tests can never entirely reproduce actual conditions, and the best that can be done is to establish such conditions as are practical and keep them constant for all the tests. In this way the results on one material becomes comparable with those on other materials." (op. cit., p. 535)

When limestones are to be used as aggregate in concrete in walls or in roads, it is important to know whether the limestones will disintegrate as the result of frost action. G. F. Loughlin* has described a few cases where argillaceous limestones were used in concrete work and after a few years the concrete failed because of the disintegration of the limestone aggregate. The two examples most fully investigated were both in southwestern Pennsylvania. One is the Allman quarry, one mile south of Clarksville, Greene County, and the other is in Westmoreland County. Both quarries were operated for crushed stone which had been accepted for highway use as the materials met the standard specifications. Nevertheless a concrete road and a retaining wall where the stone had been used went to pieces after a few years and the cause was traced to the disintegrating effect of the limestone aggregate. Careful microscopic work showed the presence of considerable argillaceous matter, especially the mineral beidellite, which has high adsorptive and absorptive properties. The rock fragments in the

*Loughlin, G. E., Usefulness of petrology in the selection of limestone: Rock Products, vol. 31, No. 6, pp. 50-59, 1928.

concrete road were wet after each rain and with the clay absorbing an undue amount of moisture the rocks were shattered after a limited number of freezings. The limestones are the rather typical fresh water limestones of the Coal Measures of the western part of the State. These studies have shown the necessity of making careful investigations of any limestone of an argillaceous character if it is to be used in any place where there is much moisture and occasional freezing conditions.

"A method, which consists in crystallizing a salt in the pores, is sometimes used for simulating the effects of frost action. This is done by soaking the stone in a salt solution and then drying it to cause the salt to crystallize. The crystals in forming cause internal stresses in the stone somewhat like that of frost. The salt which has been mostly used for this purpose is sodium sulphate. The information available on the action of this salt indicated that it causes a very severe action, and that many materials are disintegrated by a few repetitions of the operation. While the test is assumed to produce only a physical action, there is evidence that in some cases there is a chemical action as well. Due to the fact that this salt crystallizes in three common forms —namely, Na_2SO_4, $Na_2SO_4.7H_2O$ and $Na_2SO_4.10H_2O$—it appears that the conditions of test must be carefully controlled in order to insure the formation of a particular type of crystal, since a variation from one to another may cause variable results.

"Since a test[1] of this kind is very desirable in some respects, a rather extensive series of tests was made to determine if sodium chloride would prove more satisfactory than sodium sulphate. This crystallizes in only one form and appears to be free from chemical action on such materials as limestone. Tests were made with a 15 per cent solution of this salt by soaking the specimens in the solution for 17 hours and drying them in an oven at 110°C. for 7 hours. It was found that certain limestones which were disintegrated by 30 repetitions of this process would require from 210 to 300 freezings to produce the same amount of decay. Certain other limestones indicated a greater resistance to the crystallization test than to frost action. This lack of agreement with the freezing test indicated that the results are not reliable for judging weathering effects. It may however, afford some information in regard to how a material would resist the disintegration effects of efflorescence."

Changes in temperature without freezing. In arid climates a common cause of rock disintegration is the sudden heating or cooling of rock surfaces resulting in the breaking loose of curved sheets or slabs. The process is called exfoliation. Even in Pennsylvania this is effective in the breaking up of some of the igneous and metamorphic rocks, but it has little effect on the limestones. It has been noted in the case of some buildings where walls have been highly heated by serious conflagrations and suddenly cooled by streams of water, but granites and other kinds of rocks show far more pronounced effects than do the limestones.

Kessler and Sligh[2] discuss their investigations of this subject in the following quoted paragraphs.

[1] U. S. Bureau of Standards, Tech. Paper 349, pp. 543-544.
[2] Kessler, D. W. and Sligh, W. H., U. S. Bureau of Standards, Tech. paper 349, pp. 522-26, Washington.

"The thermal expansion of limestone is of considerable importance in a structural way, especially when limestone is used in connection with materials which expand at an appreciably different rate. Limestone does not expand at a constant rate for different temperature ranges. At ordinary diurnal temperatures the coefficient of expansion is much less than at high temperatures. Features of particular interest in this set of measurements are the increase in rate of expansion as the temperature increases and the permanent increase in length due to heating. Many of the coefficient of expansion values for stone found in various tests and handbooks are based on measurements at temperatures considerably above the usual climatic temperatures, hence they are too high for use in calculating ordinary structural movements. Seasonal temperature ranges of 40 to 50°C. are not uncommon, and coefficient measurements for this temperature range are of most interest. A few measurements have been made on samples of Indiana limestone for this report over the range of 20 to 50°C., which indicate an average linear coefficient of 0.000005 for this material. While this indicates a comparative low expansion, it is sufficient to produce appreciable movements or stresses in a structure. Thus, the movement in 100 feet of limestone masonry for a temperature rise of 50°C. can be computed as follows:

$$100 \times 12 \times 50 \times 0.000005 = 0.3 \text{ inch}$$

"Probably the most important consideration in connection with structural movements due to temperature changes is what happens when two materials are used which have different coefficients of expansion. Suppose a steel frame building faced with limestone is erected in summer when the temperatures are 80°F. or 26.5°C. In winter the temperature may drop to —20°F., or the equivalent of a change of 55°C. The contraction of the limestone per 100 feet will be

$$100 \times 12 \times 55 \times 0.000005 = 0.33 \text{ inch}$$

and that of the steel frame

$$100 \times 12 \times 55 \times 0.00001 = 0.66 \text{ inch}$$

The difference of 0.33 inch per 100 feet would cause both the steel and the limestone to be stressed, the limestone being compressed and the frame subject to tension; but for the elasticity of the materials one or the other would be ruptured. The amount of stress caused in either material will depend on the relative amounts of the two materials at any section and the modulus of elasticity values. One may compute the maximum stress possible in either material due to this temperature drop by assuming the other to be entirely rigid. To compute the highest possible compressive stress in the limestone due to this condition, it may be assumed that it is compressed 0.33 inch per 100 feet. The modulus of elasticity of limestone may be taken as 5,000,000. The expression $E = \frac{Wl}{Ae}$ gives the relation between the factors under consideration; that is, E = modulus of elasticity, W = load in pounds, A = stressed area in square inches, e = total change in dimension over the length l. As it is assumed that each 100 feet of stonework is com-

pressed 0.33 inch, e = 0.33 inch and 1 = 100 x 12 = 1,200 inches. To obtain the compressive stress in pounds per square inch, let A = 1 and substituting the values for A, E, e, and 1, one obtains

$$5{,}000{,}000 = \frac{1{,}200\ W}{0.33}$$

from which W = 1,250 lbs./in. (In general, the stress in the limestone caused by such conditions would be less than this due to the fact that the steel frame is not rigid and would, hence, compensate for part of the movement. Furthermore, the steel being inclosed it is not apt to reach as low a temperature as the stonework.)

"This stress is considerably above that caused by dead loads in the tallest structures, but is still well below the usual strength of limestone. Hence, it may be safely assumed that the limestone could take all of the compression under such conditions without failure, providing the loads were not concentrated on certain blocks of stone or parts of blocks. However, it is doubtful if such stresses are ever uniformly distributed, and some parts of the masonry are apt to be stressed above this amount. Spalling may occur where the vertical joints are not well filled with mortar, because such a condition would concentrate the stresses along the edges of the blocks.

"The coefficient of expansion values indicated by the test of Indiana limestone for different temperature ranges are as follows:

Derived from the heating curve:

From 25 to 100°	0.000009
From 100 to 200°	.000017
From 200 to 300°	.000022

Derived from the cooling curve:

From 300 to 200°	.000015
From 200 to 100°	.000014
From 100 to 25°	.000010

"An examination of the available data on the thermal expansion of various types of stone shows the following ranges:

Limestone (20 to 100°C.)	4.2 to 22 $\times 10^{-6}$
Marble (20 to 100°C.)	3.6 to 16 $\times 10^{-6}$
Quartzite (20 to 100°C.)	16.0 $\times 10^{-6}$
Sandstone (20 to 100°C.)	5.0 to 12 $\times 10 \times ^{-6}$
Slate (0 to 100°C.)	9.4 to 12 $\times 10^{-6}$
Granite (20 to 100°C.)	6.3 to 9 $\times 10^{-6}$

ACTION OF PLANTS AND ANIMALS

Plants and animals are effective agents of rock decomposition and disintegration both with and without chemical changes. They are effective partially because of their own actions and partially because they make or enlarge openings into which solutions can pass and dissolve the rocks. The roots of plants penetrating cracks in the rocks or the trunks of trees growing in crevices may exert sufficient force in the process of growth to break the rocks still further. On

their decay, the cavities may permit easy access for water which is an important solvent of limestones. Burrowing animals, worms, rodents, and other forms, act in a similar way to permit easy ingress of water to the rocks lying beneath the soil cover.

Plants act more directly in the decomposition of limestones in that the roots exude an acid sap which by actual experiment has been shown to have the power to dissolve calcium carbonate. A polished marble surface that has been in contact with plant roots for some time will almost invariably show etching effects. In old cemeteries one can often note marble tombstones in which the letters are now almost obliterated and others in which the depressed markings are occupied by different species of lichens. If the lichens are allowed to grow from year to year the polish of the marble and eventually the inscriptions are completely destroyed. The lichens themselves seem to secrete some organic acids that dissolve the marble and in addition they tend to hold moisture which will accomplish some work of solution. F. J. North* discusses the action of lichens and bacteria in the following paragraphs.

"Although in the open country lichens and mosses play an important part in promoting the disintegration of rocks, in towns the former are rarely met with and the latter do not usually flourish on rock surfaces that are exposed in buildings. Lichens attach themselves by fine hairlike 'hyphae' that act the part of roots and that penetrate into minute cracks in the stone. In the case of a calcareous rock, the acids produced during the growth of the plant dissolve portions of the stone, and, quoting from Kerner von Marilaun, who investigated the relation of lichens to rock decay,

> " 'a growing hypha penetrates wherever the merest particle of carbonate of lime has been dissolved, and accomplishes regular mining operations at the spot. Particles of the carbonate not yet dissolved are separated by mechanical pressure from the main mass, and at the places where a lichen is in a state of energetic growth tiny loose fragments (of calcite) are seen, which are washed away by the next shower or else are carried off as dust by the wind.'

"Only relatively hard and durable rocks can support lichens which are rarely, if ever, seen on those that are soft and crumbly and it has been remarked that 'if a stone is so liable to superficial crumbling that lichens cannot ensconce themselves, it has no business on any building.' The rarity of lichens in industrial towns is, no doubt, due to the fact that the acid-laden atmosphere and the other 'urban' agents of destruction produce a crumbly surface on stones that in rural areas afford an ideal habitat for those lowly but interesting plants.

"The known fact that bacteria play a large part in the formation of soil from rock debris suggests that bacteria may also, in some cases, be responsible for the decay of building stones, and the matter has received the consideration of the Stone Preservation Committee of the Department of Scientific and Industrial Research. At least twelve different kinds of bacteria were found in various samples of weathered stone, and the report continues:—

*North, F. J., Limestones, their origins, distribution, and uses: London, New York, 1930, 467 pp.

"'On isolating the bacteria from certain specimens of weathered stone, the colonies which developed on the plate were all of one kind. This fact, sufficiently significant in itself, was rendered still more so when on investigation it was found capable of making luxuriant growth upon an artificial medium so poor in organic food material that the life of other bacteria was barely supported. This instance alone encourages the belief that a full investigation of the biological aspects of stone decay is warranted and should be pursued with the utmost vigour.'

"It would seem that limestones are specially subject to bacterial decay, for the organisms derive their nourishment from the nitrogenous compounds, such as ammonia, present in rain water, and the ammonia is converted into nitric acid which readily dissolves calcareous rock or cementing material; this process accounts for the decay of limestones and calcareous schists in the highest Alpine region where no life exists, except certain kinds of bacteria.

"Bacteria also decompose organic matter, setting free carbon dioxide, which, as we have previously seen, converts water into a weak acid capable of dissolving limestone."

If the atmosphere of the region contains much carbon dioxide and sulphur gases, such as is common in manufacturing centers where coal is burned in large quantities, or about cities, the decomposition of marble is so rapid that certain cemeteries recommend that marble be not used as grave markers. "The air of industrial towns often contains compounds of sulphur derived from the smoke of coal, and these, in the form of sulphuric acid combine with calcium carbonate forming calcium sulphate. The waste gas from the burning of a ton of average coal contains from 30 to 50 pounds of sulphur, from which it will be seen that the amount of sulphurous vapours discharged into the atmosphere of a large industrial town is very great. If the effect of these gases upon limestone stopped with the formation of calcium sulphate little serious harm would be done because the product of the alteration is but slightly soluble in water, but the newly formed salt tends to crystallize, and since the volume of the crystals of gypsum is 20 per cent greater than that of the calcite from which they were derived, the surface layers of the stone are shattered, thus promoting the disintegration of the rock and the exposure of fresh material to the same destructive influences.

"The process may be even more destructive in the case of dolomitic limestones, because the magnesium sulphate produced during the change is soluble in water, and its removal leaves the surface layers of the stone in a friable condition; this was illustrated in the case of the Houses of Parliament. The fact that similar dolomitic limestone was also used at about the same time in the building of the Museum of Practical Geology, and has withstood well the ravages of the weather, indicates that the rock is not of necessity unsuited for town use, provided that, as was the case with the stone for the latter building, adequate experience is brought to bear upon the selection of the beds to be quarried and of the actual blocks to be used.

"That changes, such as those described, are in progress, is often indicated by the appearance of a white powdery growth or florescence on the surface of the stone. The material, sometimes known to build-

ers as 'wall-white', usually consists of calcium, magnesium, and sodium sulphates, but its composition may in some cases be influenced by the associated mortar or cement."*

Where the stones are kept clean, free from plant growth and dust, and the atmosphere is clear as in most country districts, marble is one of the very durable materials.

SOLUTION

More important by far than all the other well-known processes of limestone decomposition and disintegration combined is that of solution. Pure water will slowly dissolve limestone but naturally the water that comes in contact with the limestones is not pure. It almost invariably contains carbon dioxide and in regions of much vegetation various humus acids. These materially increase the soluble action of the water.

Magnesian limestones and dolomites are generally believed to be less soluble than the high calcium carbonates and yet actually this does not always seem to be the case. In certain regions known to the writer where interbedded low and high magnesian limestones outcrop, solution has extended deeper in the high magnesian layers so that the soil cover may conceal practically all the high magnesian strata and only partly cover the others. This situation is of great economic importance if one is searching for either one of these types of stone and desires to avoid the other. Whether this is entirely due to the greater number of cracks in the dolomitic beds or whether it is due to greater solubility on account of the presence of certain acids is not known to the writer. It is a matter that warrants investigation.

Rain falling on the limestones will accomplish some solution; water standing on the surface and filling any depressions will do more; but most of the solution takes place after the water has passed through the soil. Soil water is held in close contact with the limestones and contains humus acids which facilitate solution.

Limestones are much less durable in moist regions than in dry ones. If in addition to the moisture, there is a larger percentage of carbon dioxide than normal and perhaps also dust particles that collect on the surface and hold the moisture, limestones are dissolved very rapidly. The atmosphere of London with its dust particles, fogs, and excessive content of carbon dioxide is frequently cited as especially unfavorable for limestone preservation and some of the older marble statues standing in the open are now minus fingers, noses, and other projecting points. On the other hand, limestones are particularly resistant in dry countries. Some of the Basin Range mountains in Arizona, Nevada and New Mexico contain limestones which have resisted erosion more than the other sedimentary rocks.

Water falling on the surface as rain and water that comes from the interior of the earth especially in the region of volcanoes and in places where the rocks have been broken deeply by mountain-building disturbances, circulates through the rocks and may pass through beds of limestones by slow percolation. Most of it, however, flows through the cracks (joints) or between the different layers and as it moves in these openings takes limestone into solution until the point of saturation is reached. Every limestone region after a time becomes cavernous.

*North F. J.: Op. cit.

If the openings are large they are called caves. Wherever their is a thick deposit of limestones, there are sure to be caves and in Pennsylvania there are many, some of which are of considerable size and contain cave formations of great beauty. R. W. Stone[1] of this Survey has written a bulletin on the Pennsylvania Caves to which interested persons are referred for more complete information.

In many sections where caves have not been discovered there is evidence of the underground caverns in that surface water quickly finds its way below the surface by flowing into depressions or sinks. Saucer-like depressions commonly called ''limestone sinks,'' in which there is no water, even immediately after heavy precipitation, are common features of limestone regions and indicate the presence of underlying limestones in places where other surface indications are lacking.

A common practice that has not yet entirely ceased is for the residents of the greater limestone valleys of the State to depend entirely upon the underground caverns and passages for the disposal of house sewage. Before a house is built a well is sunk to locate cavernous rock which may be found within 15 or 20 feet in some places, but in others these wells may be 50 or 60 feet deep. Occasionally several holes are dug before a satisfactory one is secured. All house sewage is led into these openings and usually it finds its way through devious courses to the streams. It generally undergoes such thorough decay by bacterial action that the streams do not seem to be as badly polluted by this custom as one might expect. In some instances the holes later become clogged by the sewage and new holes must be dug, but generally the caverns are sufficiently large and open to serve their purpose satisfactorily year after year. Properties where sewage disposal by this method has not been successful are known to have been sold at much less than the cost of the improvements. One instance is known to the writer where the directors of a charitable institution with more than 50 inmates assumed that the property was underlain by limestones, as was that of nearby lots, and made efforts for disposal of sewage in this way only to find later that the underground rock was gneiss and void of caverns. It will be long before this practice by which the underground waters are polluted will be entirely abandoned, although all of the towns of Pennsylvania located in limestone areas are gradually building municipal sewage systems such as have long been in use in other communities.

Oxidation of accessory minerals. A limestone containing easily oxidizable substances such as iron sulphides or organic compounds will undergo changes on exposure to the air. In the oxidation of pyrite and marcasite, sulphuric acid is formed which readily dissolves the stone. The main effect of oxidation, however, is change in color, which is discussed in the next topic, but if iron sulphide is present in large quantities which is rarely the case, and is removed by solution following oxidation, the limestone may be materially weakened.

DISCOLORATION

Kessler and Sligh[2] report the results of investigations on the discoloration of limestone. Some of their conclusions are quoted.

[1] Stone, R. W., Pennsylvania Caves: Pa. Top. and Geol. Survey, Bull. G3, 100 pp., 1932.
[2] Kessler, D. W. and Sligh, W. H., U. S. Bureau of Standards, Tech. paper 349, Washington.

"In the discussion of this subject the term 'discoloration' is considered as any change from the natural color other than that caused by surface deposits of soot or grime which are apt to collect on any building. The kinds of discoloration which may mar the appearance are as follows: First, local stains caused by the absorption of extraneous matter from other parts of the building or carried into the stone by ground water; second, alteration of certain mineral ingredients of the stone where exposed to the weather; third, impurities in the stone leached to the surface by percolating waters.

"Limestone in general is apt to be discolored from the first-named cause, while only certain deposits appear to be appreciably affected from the second and third. Usually those limestones containing minerals which are altered at the surface change color rather uniformly, and the change is often desirable rather than unsightly. Several limestone deposits contain a sufficient amount of organic matter in the form of oil or bituminous matter which comes to the surface as the stone seasons, producing undesirable discolorations. In many cases such discolorations are temporary and are soon carried away by rain. Occasionally, under certain conditions in the structure a large amount of this discoloring matter is leached from the stone, producing ugly brown or almost black spots which do not disappear of their own accord and are very difficult to remove by cleaning processes. These discolorations are a great source of annoyance and the fact that any particular deposit is subject to such is apt to detract from its otherwise desirable qualities. Such discolorations are sometimes erroneously called iron stains because of their resemblance to iron rust."

"Tests have indicated that any particular kind of mortar may produce variable results when used on several blocks of limestone from the same quarry. This fact seems to show that the organic impurity in the stone varies from one point to another or occurs in segregated masses. The same conclusion may often be drawn from observation of the way limestone discolors in buildings. A particular block in the wall sometimes discolors badly while adjacent blocks are not appreciably changed."

"The tests all indicate that the stain which is developed on Indiana limestone on exposure to the air and to water containing alkali from mortar is of an organic nature. The organic substance present in a very small amount (about 0.1 per cent) in this stone is related to bituminous coal.

"Probably the discoloring matter is altered after exposure to air because old stains of this kind on buildings are very difficult to remove."

"The most plausible explanation of such discolorations on limestone is that water in leaching through the masonry becomes somewhat alkaline in passing through the mortar, and thus acts as a solvent on a part of the organic impurity in the stone. This solvent action of caustic solutions on organic matter is frequently made use of in detecting the presence of organic impurities in sand."

"Some limestones contain an appreciable amount of oil which comes to the surface as the stone seasons. This causes a rather uniform murky appearance until the oil has evaporated, after which the stone assumes its natural color. This type of impurity in limestone does not readily respond to the test with sodium carbonate, but

it may be determined by soaking a handful of the stone fragments a few days in a bottle of benzol. The oily matter is diffused through the benzol, giving a brown color.

"The question of how to prevent discoloration on limestone is frequently asked. Probably the best recommendation that can be made in this connection is to prevent excessive percolation of water through the masonry. Observations usually show that a common condition which causes discoloration is that of starting the limestone work below grade. Limestone being a rather porous material, it allows a great deal of moisture to rise by capillarity through its pores when in contact with moist soil. Under such conditions a large percentage of limestone buildings develop discolorations on the first two or three courses above the ground level. To prevent this, a grade waterproofing may be used, in which case one should be selected that is known to be durable. Doubtless the best means to prevent discoloration on the lower courses of limestone is to use a granite foundation or one course of granite extending through the wall at or somewhat above grade. A thin course of slate has been employed to some extent and appears to be an excellent material for the purpose. Other parts of buildings subject to excessive staining are those immediately below projecting courses, as the cornice and water table. Frequently the roof drainage system becomes faulty, allowing the walls to become saturated at various points, which condition is apt to produce discoloration. Obviously, the remedy in the last case is to repair the drainage system. Discolorations below projecting ledges may be largely overcome by sealing the vertical joints with a good mastic cement and waterproofing the top face of such courses with a colorless waterproofing."

In addition to the above statements by Kessler and Sligh, it should be stated that almost all the dark-colored limestones become much lighter in color on exposure. In the State, we have some limestones that are almost black when fresh on account of the large amount of organic matter which they contain. On exposure to the oxidizing effects of the atmosphere they finally assume a muddy gray color.

The light to dark bluish limestones of the Paleozoic formations almost invariably become whiter on exposure. If the rocks are of uniform texture this change of color is even and the effect pleasing. If, however, they are conglomeratic a mottled effect is very apt to be produced as the fragments may change to one shade and the cementing matrix to another shade. This condition has been noted in a number of varieties of limestone in which the fresh rock appears nearly uniform and its conglomeratic character is scarcely noticeable except on the weathered surfaces.

EFFLORESCENCE

The efflorescence on limestone surfaces has received little attention. It also has been investigated by Kessler and Sligh* and some of their results are quoted.

"The disintegrating effect of efflorescence on masonry has often been pointed out by various authorities, but its importance has probably never been fully appreciated. Efflorescence is more often regarded as merely a disfiguring deposit of salts on the surface. How-

*Kessler, D. W. and Sligh, W. H., op. cit.

ever, an examination of the surface where such deposits occur will sometimes show an appreciable amount of decay if not a deep spalling or crumbling of the masonry.

"Efflorescence is a growth of crystals on the surface and in the pores of the masonry where a salt solution evaporates. The solvent carrying the salt is probably always water. The source of the salt may be varied, but in most cases it is leached from the masonry walls by water as it slowly percolates through the pores. No building material is entirely free from water-soluble salts, and the small amounts of such which usually appear in chemical analyses as a few tenths of 1 per cent are sufficient when leached out and concentrated at some point on the surface to cause efflorescence. It may also be caused by salts carried by ground waters, and the efflorescence frequently seen on the lower courses of buildings is more apt to be due to this cause. Soot which collects on roofs and horizontal parts of masonry always contains a small amount of water-soluble material which may be leached into the masonry by rains."

"The composition of the salts causing efflorescence may be as varied as their source. Any salt that is soluble in water even to a very slight degree may be finally dissolved and leached to the surface under continued damp conditions. Even a part of the calcium carbonate of limestone is sometimes dissolved when water trickles down between the stone facing and masonry backing. When the solution finds its way to the surface and evaporates, a crust or stalactite may be formed on the exposed surface."

"Samples of efflorescence collected from limestone masonry accompanied by disintegration gave the following composition.

	No. 5	No. 6
SiO_2	0.28	2.20
Fe_2O_3 and Al_2O_3	.10	3.00
CaO	31.30	46.90
MgO	1.33	trace
SO_3	42.32	5.40
SO_2	.....	3.25
Ignition loss	25.03	34.60

The composition of these seem to be mainly water-soluble sulphates."

"Limestone itself evidently contributes an appreciable amount of soluble matter in the formation of efflorescence. The efflorescence was leached from blocks of stone with pure water. Three grams of this material were scraped from one block and found to contain the following:

SiO_2	0.28	MgO	1.33
Al_2O_3 and Fe_2O_3	.10	SO_3	42.32
CaO	31.30	Ignition loss	25.03

"The disintegration action of efflorescence is similar to that of frost. When the solution of salts evaporates, the salts are left behind and form crystals. Some of the crystals develop in the pores of the stone and in their growth exert a wedging action which gradually pries loose small fragments from the surface. This action is far more severe and shows its effects more rapidly than frost, although it manifests itself in a different way. A stone when frozen in a water-saturated condition may be subjected to stress all the way through and it may

be disrupted along a seam of weakness, although this seldom occurs except with freshly quarried blocks. In the case of efflorescence the wedging action is only near the surface, since crystals will necessarily be on the surface and no decay will ensue. For this reason one frequently finds that the masonry near the ground level is in good condition while at a certain height above the ground a zone of decay is noted. This is evidently due to moisture rising from the ground which keeps the lower part continually damp, but where the damp condition ceases the crystals of dissolved matter form in the pores."

CHAPTER V

CHARACTERISTICS OF LIMESTONE REGIONS

Limestone regions have certain characteristic features by which one can be sure of the presence of limestone although no rock is exposed. These features are mainly due to the ways in which limestones weather, the readiness with which they undergo chemical changes, and the results of such weathering. Under this heading, the following topics related to limestone areas are therefore discussed: 1. Underground and Surface Waters; 2. Topographic Features and Their Utilization; 3. Soils; 4. Metallic Ore Deposits associated with Limestones.

UNDERGROUND AND SURFACE DRAINAGE

A topographic map of an area underlain in part by thick limestones and in part by less soluble rocks presents striking features. Major surface streams and numerous tributaries are characteristic of the regions underlain by the relatively insoluble rocks whereas the limestone areas may have no surface streams or only the major ones. A number of the topographic maps of the State present these striking contrasts. Of course, the explanation is that the surface water of the limestone areas quickly passes underground into the caverns of a subterranean drainage system.

The problem of securing ample supplies of good well water in limestone regions has become a serious one in many sections. The limestones themselves are relatively impervious so that little water passes through them and the solution channels permit most of the ground water to collect in definite subterranean streams. Accordingly when a well encounters one of these major streams an unfailing and almost unlimited supply is obtained. In some cases these streams emerge at the surface, as illustrated by Boiling Springs and Big Spring in Cumberland County which form fair-sized creeks. If a well fails to strike one of these streams it may furnish practically no water regardless of its depth. There are extensive areas in the great limestone valleys of Pennsylvania where the farmers depend entirely upon cistern water for their domestic supply.

The quality of the water obtained from limestone is a matter of considerable concern. Almost invariably it is "hard," that is, heavily charged with $CaCO_3$, rendering it highly undesirable for boiler purposes and unsatisfactory for most uses. It is also likely to be contaminated on account of the open character of the channels and the ease with which surface water passes underground with a minimum of filtration.

TOPOGRAPHIC FEATURES

As a result of solution by water, the areas underlain by thick beds of limestone have been reduced to lower levels, leaving the less soluble rocks, particularly the quartzose and igneous or metamorphic noncalcareous rocks to form the ridges. This is true regardless of the structure of the rocks.

The major valleys of Pennsylvania lying east of the Allegheny Front are mainly underlain by limestones and shales. The Cambro-Ordovician limestones of Pennsylvania because of their great thickness and their

easy solubility compared with the rocks both above and below, are among the important valley-forming rocks of the State. The Great Valley that extends across the State, with a southwesterly trend, from New Jersey to Maryland is underlain by Ordovician shale and Cambro-Ordovician limestones; the part underlain by limestone presents a good example of a limestone valley and contains the thriving cities of Easton, Bethlehem, Allentown, Reading, Lebanon, Steelton, Carlisle, Chambersburg, and scores of smaller towns and villages. In New Jersey this valley is designated the Kittatinny Valley; between the Schuylkill and Susquehanna rivers it is known as the Lebanon Valley; and southwestward from Susquehanna River it is called the Cumberland Valley. In Maryland and Virginia, it is known as the Shenandoah Valley.

The widest valley floored by the Cambro-Ordovician limestones is the rich and fertile Lancaster Valley which comprises fully one-half of Lancaster County. An extension of this valley through York and into Adams County is known as the York Valley. In it are the cities of York and Hanover. The beautiful Chester Valley that extends from Montgomery County southwestward through Chester and Lancaster counties is narrower than the others. It includes the towns of Conshohocken, Downingtown, Coatesville, Quarryville, and many others. In the central and south-central parts of the State a number of Cambro-Ordovician limestone valleys have been developed in Clinton, Centre, Blair, Huntingdon, and Bedford counties.

The Cambro-Ordovician valleys lie southeast of the Allegheny Front, that is, in the region where the rock strata have been compressed into great anticlines (upward folds) and synclines (downward folds). Immediately after the folding, provided erosion did not keep pace with it, the anticlines formed the ridges and the synclines the valleys, regardless of the kind of rocks exposed at the surface. In time, however, erosion lowered both the former valleys and also the former ridges to a base level which was not far from sea level, below which the streams could not cut and carry away the resulting debris. The region was then a featureless low-lying plain, termed a peneplain, with nothing to distinguish the former locations of the hills and valleys nor the distribution of the harder (more resistant) and the softer (less resistant) rock strata.

At a later period the entire State of Pennsylvania and surrounding regions were uplifted, erosion was revived, and the streams rejuvenated sufficiently to carry away the disintegrated portions of the rocks. When this occurred the places where limestone strata were exposed were lowered more rapidly than the less soluble rocks and they have ever since remained as valleys.

Some examples of what are called anticlinal valleys are Nittany Valley in Centre County and the Nippenose Valley in Lycoming County, where the rocks have been upfolded forming anticlines, but with the center of the folds now forming the valleys. This is due to erosion having worn away the siliceous rocks that once capped the highest portions of the folds and then opening up valleys of solution in the underlying limestones.

Although the Cambro-Ordovician valleys are such prominent topographic features throughout the southeastern and south-central parts of the State they are not followed by the major streams. The larger

streams had established their southeasterly courses before the uplift that followed peneplanation and with few exceptions they maintained their old channels. Thus nearly all the larger streams with prevailing southeasterly courses cut across these limestone valleys that, in general, trend northeast-southwest. Minor streams occupy the limestone valleys but they are not particularly conspicuous because so much of the drainage of these valleys is by means of subterranean channels. All of the larger, more continuous limestone valleys have afforded easy routes for highways and for railroads and for this reason many of the towns and cities located in these valleys have become important manufacturing centers.

The limestones of the western part of the State occurring as thick or thin beds alternating with much greater thicknesses of shales and sandstones and some coal beds and all lying nearly flat have not materially affected the topography. Only in quite restricted localities can one notice their effect.

In some regions, as for example the Tyrol of the eastern Alps, a type of topography designated as "karst" has been developed by irregular and deep differential solution. Sharp pinnacles and steep depressions produce a highly picturesque topography of considerable relief. This is practically absent from the limestone regions of Pennsylvania except on a minor scale. In some quarry operations the surface clay soil extends downward into pockets or wells of solution that may seriously interfere with economic quarrying. The upper portion may be removed by drag line excavators or scrapers but the deeper portions of the narrow pockets must be excavated by pick and hand shovel. When the limestone in such an area has all been removed the surface is very irregular and on a small scale is karst topography. Some of the clay pockets may be 20 feet or more in depth.

SOILS

Limestone soils have long been known to be fertile and to favor agriculture. The most highly developed agricultural districts of Pennsylvania are those of the great limestone valleys. In few places anywhere can one find more fertile soil or finer farms than those of Lancaster County, for example, where the soils are derived from limestone.

The original soils of a limestone district consist of the insoluble constituents of the limestones which have been left as residues when the soluble carbonates were carried away in solution. Where the limestones were fairly pure a large amount of stone was decomposed to form a comparatively thin layer of soil. Where the limestone region is fairly flat and the surface run-off of rain water is slight most of the residual material remains, whereas on steeper slopes or above noncavernous rocks the residual material is apt to be carried away by surface streams. There are some areas, however, in the great limestone valleys where the limestone soil is thin and the lands are better adapted for grazing purposes than for cultivation. Portions of the Cumberland Valley between Susquehanna River and Maryland show very thin soils and much limestone appears at the surface. In many places the limestone soils have been augmented by material brought in from adjoining regions by winds, streams and glaciers and in a

few places in such amounts as largely to mask the original limestone soils.

Limestone soils are colored red and yellow by the oxides of iron; the iron was present in the original limestones in small amounts either in oxide form, or more commonly as carbonates or sulphides. In the latter case these compounds have oxidized during the decomposition of the rocks. The soils are fine-grained, due to the fine state of division of the rock impurities and when wet are plastic. They are well adapted to the growth of corn, grass, and small grain and constitute the most important agricultural soils of the State. They are also suitable for the manufacture of brick and tile and have been utilized for these purposes in many parts of Pennsylvania.

METALLIC ORE DEPOSITS ASSOCIATED WITH LIMESTONES

Limestone is of extremely great importance in many sections of the world because of its effect in the formation of certain metallic ore bodies. Lead and zinc ores are more commonly associated with limestone than with any other kind of rock and ores of iron and manganese are common to it.

In Pennsylvania, zinc ores were formerly extensively worked at Friedensville, Lehigh County, where they occur as replacements of, and fracture fillings in, the Ordovician magnesian limestone. At Landisville, Lancaster County, and Birmingham, Blair County, lead and zinc ores have also been worked in the Paleozoic limestones. There are a number of other places in the State where lead and zinc minerals have been found in limestone but not in sufficient quantity to justify the opening of mines.

Residual limonite ores have been mined in hundreds of places in the limestone valleys of the State. In some cases the ore bodies covered extensive areas, extended to depths of 100 to 200 feet, and contained tens of thousands of tons of ore. The iron industry of Pennsylvania was mainly dependent upon this class of ore for many years but its importance gradually declined as improved transportation facilities permitted the importation of high grade Lake Superior and Adirondack ores. For several years past all these limonite mines have been idle. Ochre was found in association with the limonitic iron ore and some of these deposits are still operated at intervals by paint manufacturers.

The limonite and ochre in the limestones owe their origin to the action of ground water that removed the soluble carbonates and concentrated the iron compounds originally disseminated throughout the strata. The concentration was most pronounced in shattered zones of the limestone where there was free circulation of the ground water.

The oxidized ores of manganese and iron are commonly found in association. In this State manganese ores are of little consequence but manganiferous limonite ores in the past were worked in many places. Umber, which is manganiferous ochre, has been mined in several localities within recent years.

The ore body of the Cornwall iron mine in Lebanon County, the most important iron mine ever developed in Pennsylvania, owes its origin partly to the presence of a great thickness of Paleozoic limestone. A dike of igneous rock brought up the iron-bearing solutions,

or else prepared the way for solutions, which have replaced the limestone by magnetite for a considerable distance from the contact. The ore body thus formed has already yielded more than 34,000,000 tons of ore. The ore also contains appreciable amounts of copper, cobalt, silver, and gold. In the past, other iron ore bodies of a similar character have been worked in the State.

A stratum of siderite (iron carbonate) ore ranging in thickness up to 3 or 4 feet commonly overlies the Vanport limestone in western Pennsylvania. It was formerly mined on a small scale in several localities, especially in Armstrong, Butler, and Lawrence counties. This ore has been formed by the replacement of limestone by descending ground waters carrying iron in solution. The iron ore contains fossils just as does the high grade limestone beneath it.

Ores of copper formed by replacement of limestone are of great importance in Southwestern United States but of no consequence in Pennsylvania, although traces of copper have been noted in some of our limestones.

CHAPTER VI

USES OF PENNSYLVANIA LIMESTONES, DOLOMITES AND MARBLES

In the discussion of uses of limestones, dolomites, and marbles it must be recognized that for certain purposes only one or two of these can be employed, whereas for other uses it is immaterial which one is taken. In some cases the choice depends upon the chemical or mineralogical composition and in others upon some of the physical characteristics. Although for specific uses one particular kind may be preferred, another is frequently substituted if cheapness, accessibility, or some other economic factor enters into consideration.

Ordinarily the uses of limestone, dolomite, and marble are discussed separately but such treatment involves considerable repetition inasmuch as these different substances may be used interchangeably or in various combinations in numerous cases. The variety of uses for limestone and limestone products is so great that it is inadvisable to attempt a complete description in this place, and only the principal uses will be described. As there are many different opinions in regard to the comparative value of these materials for various uses, one can only present the different points of view and wait for the accumulation of more data before reaching a final conclusion.

A general outline of uses that will be discussed is presented. It should be recognized that it is extremely generalized and that there are exceptions and additions not mentioned.

Table of Uses

	Limestones	*Dolomites*	*Marbles*
Structural purposes, buildings, etc.	X	X	X
Decorative purposes, interiors			X
Crushed stone			
Road metal	X	X	?
Railroad ballast	X	X	
Aviation fields	X	X	X
Concrete	X	X	X
Pulverized stone			
Filler	X	X	X
Paint	X	X	X
Glass and pottery manufacture	X	?	
Rock dusting of mines	X	X	X
Agricultural fertilizer	X	X	X
Animal food	X		X
Flux	X	X	X
Portland cement	X		?
Natural cement	X		?
Slag or puzzolan cement	X		
Open-hearth furnace lining		X	
Extraction of magnesia		X	?
Manufacture of mineral wool	X		
Lime	X	X	X

STRUCTURAL PURPOSES

Limestones and marbles have been used more extensively for building purposes than any other class of stones. Although less durable than granite they are more attractive for many purposes on account of their light color. However, their extensive use is due mainly to

their wide distribution in almost all countries and to the ease with which they can be quarried and dressed.

The chemical composition of the calcareous stones used in buildings and other structures is of no particular importance unless there is present some objectional chemical substances or minerals such as pyrite, marcasite, or other easily decomposable minerals or hard minerals such as quartz or flint that might seriously interfere with sawing and dressing the blocks. The requisite qualifications are practically all physical. The first requirement is a desirable color but this is possessed by nearly all limestones and dolomites. The stone must be sufficiently strong to bear the weight of the overlying blocks. This requisite is easily met by nearly all limestones, although in some cases as, for example, the Washington Monument, some of the marble blocks used have broken but probably because of unequal distribution of the load. The material must also be durable in the place and for the purpose used. In addition, it is advisable and generally necessary for economic reasons that the beds be regular in thickness, neither too thick nor too thin, have comparatively smooth bedding plane surfaces and the joint planes be regularly spaced and far enough apart to permit the quarrying of blocks of a size suitable for structural use.

Some quarries in the State contain stone fulfilling all of these requirements. In most places, however, there are some unfavorable features so that Pennsylvania has never developed an important structural limestone industry. Except in the earliest settlement of the various sections when stone residences and barns were constructed, the limestones have been quarried mainly for other purposes. Hundreds of attractive stone buildings in the State are constructed of native limestone, but nearly all of them are old. Most of the modern stone buildings are built of other materials or, of limestone or marble obtained outside the State. The reason for this is that nearly all the durable limestones of the State desirable for structural purposes are found within those sections that have been subjected to such severe compression by the great earth movements of the past that it is not economical to develop quarries for building blocks. The strata have been intricately folded and faulted and joints are apt to be so closely spaced and so irregular as to make it difficult to obtain blocks of satisfactory size and shape. In addition, the Pennsylvania limestones which were in almost all cases accumulated in shallow water under changing conditions of sedimentation, may be gnarly in character, have uneven surfaces and variable thicknesses from very thin to extremely thick.

Nevertheless many of the limestone quarries have furnished some building stone and continue to do so even though the bulk of the product is utilized for other purposes. It is a common practice to sort out and put aside desirable building blocks in those quarries where hand loading is employed. Most of these stones are used for lining wells, for walls, foundations for houses and bridges, curbs, etc., but occasionally for the entire construction of residences.

It is not improbable that the time may come when in certain communities where favorable conditions exist, some limestone quarries may be operated with profit primarily for building stone to supply more than the local requirements. The writer feels that the other

uses of the limestones of the State have received so much attention that their use for structural purposes has been disregarded.

DECORATIVE PURPOSES

For decorative purposes, mainly in interior work, and for monuments, marble is generally preferred. The high polish which marble takes, the attractive colors, and the ease with which it can be cut, dressed and polished have all operated to make marble our most widely used decorative stone. Nevertheless there are many problems peculiar to the quarrying and preparation of marble that tend to make many operations unsuccessful. One of these that might be mentioned is the excessive waste.

Pennsylvania contains some fine marble in Montgomery, Chester, Lancaster, and York counties and also a few favorable occurrences in the Great Valley. These are discussed in the descriptions of the different counties. In the Whitemarsh and Chester valleys of Montgomery and Chester counties there are a number of old marble quarries the product from which was extensively employed in interior decoration in some of the important public buildings in Philadelphia and elsewhere, and was used also for the marble door steps formerly so popular. The stone varies from white to mottled or banded and is highly ornamental. These marble quarries have long since been abandoned or else are used to supply stone for other purposes and the State depends entirely on marble from other regions. Vermont, Tennessee, Georgia, and foreign localities furnish most of the marble used within the State.

The principal reason for this situation is that the marble bands supplying the best stone are narrow and in most cases the strata dip at high angles. Under these conditions only a limited amount of stone can be obtained before the quarries became so deep as to make quarrying costs prohibitive.

Some mottled marble of pleasing appearance occurs near York, but it has never been worked for decorative stone. Also some black Helderberg limestone or marble from Bossardsville, Monroe County, has been investigated. The stone takes a high polish and compares favorably with some of the best black marble now used but as yet no attempt has been made to exploit it.

CRUSHED STONE

In recent years the use of crushed stone for highway construction, ballast, and for concrete has been continually increasing. By far the greater number of limestone quarries in the State are worked primarily to supply crushed stone. Although less durable than granite or trap rock, most of the crushed stone used is limestone. The expense of quarrying and crushing the limestone is naturally much less and its durability is sufficiently great to warrant its use in almost all cases.

The limestones of the State, with few exceptions, are satisfactory for practically all the purposes for which crushed stone is used. Those too soft for some uses are: some of the marbles and the highest quality low magnesian limestones, the argillaceous limestones used in the manufacture of Portland cement, and some of the soft impure limestones (mainly of fresh water origin) of the Coal Measures in the western

part of the State. The great thicknesses of limestones of the limestone valleys of the central and southeastern portions are almost universally satisfactory. In places it is not profitable to quarry the Helderberg limestones because of the thin bands of interbedded shales. However, these shales normally break into fine pieces in the process of grinding and find their way into the screenings.

The dolomitic and siliceous varieties of limestone are somewhat harder than the low magnesian limestones and hence more desirable for crushed stone. Thin bedded or shaly limestones are not suitable because of their tendency to break into thin fragments or slabs that produce less strength than the irregular angular pieces when used in concrete.

The various types of machinery employed in crushing stone can not be described here. They vary from the small portable jaw crushers that are hauled from place to place to supply a small amount of stone for local use to the elaborate huge gyratory, jaw, roll and hammer mill crushers, capable of handling blocks as large as can be conveniently hauled to the crusher house. The crushing is usually done in at least two steps. After passing through the primary crusher the product is screened and the oversize conveyed to a second crusher until all is reduced to the desired size. Most plants are supplied with various sized screens so that they can furnish any size stone demanded.

The best practice is to wash the limestone in order to remove the clay which can not be eliminated entirely in the stripping or in screening. This is done in a number of plants but in many cases it is not practicable because of lack of an accessible water supply. Washed stone is always preferable because the clay of the unwashed stone not only prevents the cement from coming in contact with the stone to form a firm bond, but it is also objectionable because of its property of absorbing moisture and thus increasing the injury done by freezing.

In some quarries the clay which may adhere to the stone is largely eliminated by having the stone dumped on a grizzly before going into the primary crusher. This works fairly well when the stone and clay are dry but not so well when wet.

The finest product of a crushing plant is called screenings. Usually there is less demand for this material and it accumulates in large quantities. Its principal use has been for top dressing on roads, but ordinarily this demand is light. Experiments with this fine product in concrete in place of sand have given most satisfactory results. Some of the tests indicate a decided superiority over the standard Ottawa quartz sand. In those places where the stone is washed, the fine screenings, sizes less than one-four inch, are now being sold as sand for concrete and the market for this product is increasing. The Bethlehem Mines Corporation at its various fluxing stone quarries in Adams, Dauphin, Mifflin, and Northampton counties, is marketing this product with considerable success. A few plants making only crushed stone are also selling the fines as "sand" for concrete.

Another and well-established use for the small sizes is in the manufacture of concrete building blocks. Concrete block plants are frequently seen in the vicinity of crushed stone quarries. In at least one place an "amiesite" (ready-mixed asphaltic road stone) plant located near a crushed stone quarry is drying some of the fine screenings and mixing them with asphalt for road use.

During the past few years there have been some important developments in the crushed limestone industry of the State. One of these is the entrance into the crushed stone industry of operators who were formerly concerned only in the production of limestone for flux or for lime. Some of the fluxing stone operators formerly discarded all of the stone that broke in crushing to sizes too small for blast furnace use. Others were able to sell this product to Portland cement manufacturers if the stone had the right chemical composition. Now many of these concerns have entered the crushed stone market and not only do they dispose of their by-product, but if the demand is sufficient they crush some of the stone that might be used for flux.

Some of the lime producers are doing almost the same thing. Most of the lime used in the State is burned in upright kilns and the small sizes cannot be used. Some rotary kilns have been installed in which to burn the small sizes but there is a greater tendency to crush and size by screening the small stone and sell it for crushed stone.

It is apparent that in communities where limestone is being quarried on a large scale for flux or for lime these concerns will gradually monopolize the crushed stone market as small crushed stone operations will not be able to compete either in quality or price.

Apart from this trend there is also a tendency for the merging of small companies to form large corporations or for the development of large operations and the elimination of small inefficient plants. The ruinous competition that has prevailed in some sections, especially during the last few years when the available capacity has far exceeded the demand, has resulted in the mergers. An example of this is seen in the Reading region where all but one of the numerous operators united and by closing most of the quarries and concentrating in two quarries have been able to promote their business. Similar mergers are contemplated in other sections.

The development of large plants to the exclusion of small ones has come about mostly through the greater efficiency possible in the operation of a well equipped large plant. This means that the larger plant supplies a larger territory and consequently the product is hauled farther. Until the advent of hard surfaced roads penetrating almost all sections of the State this situation was not practicable but each year longer hauls over hard roads are being made. The limit of this large plant development is not yet in sight and it appears that many small plants still in operation will eventually find it impossible to meet the competition of the larger ones.

In a number of places in the western and northern parts of the State remote from limestone localities either other materials are used in place of crushed limestone or limestone is shipped in by rail. Naturally the quarries engaged in railroad shipping are all large operations.

Road metal. Limestone and dolomite are more extensively used for road metal than any other type of stone. Although not as hard and consequently not as durable as some materials, limestone has an advantage over these others in that the powder produced by attrition, as the traffic loads crush the particles, possesses excellent binding qualities. This is especially important in water-bound macadam roads.

Almost every hard road in the State is constructed according to specifications of the State Highway Department. The U. S. Bureau

of Public Roads and the various State Highway Departments have made careful investigations to determine the requisite qualities of stone for permanent roads and have drawn up rigid specifications and formulated tests that are fairly uniform. The tests or determinations made are usually the following: (1) specific gravity, (2) weight per cubic foot in pounds, (3) absorption per cubic foot in pounds, (4) per cent of wear, (5) French coefficient of wear, (6) crushing strength in pounds per square inch, (7) hardness, and (8) toughness. In general, these tests are the same as those employed to determine the usefulness of stone for building purposes.

All of these qualities and tests have been described in a previous chapter on the physical characteristics of limestones.

In addition to the above, any limestones that are thought to contain considerable argillaceous matter and hence are liable to easy disintegration by frost action are subjected to the freezing or sodium sulphate tests which have also been described on a previous page.

Another test, called the cementing value or binding power test, is sometimes employed. In this a sample weighing 500 grams (1.1 pounds) is crushed to pea size and then finely ground in a ball mill to the consistency of a thick dough. Cylindrical briquettes 25 millimeters (1 inch) in diameter are molded from the rock paste and thoroughly dried. A plunger on the end of the specimen is repeatedly struck by a 1 kilogram (2.2 pounds) hammer falling a distance of 1 centimeter (0.39 inch). The number of blows required to break the specimen is called the cementing value of the stone. Limestone, dolomite, and marble have high values in comparison with other kinds of rock. Over 75 per cent give values exceeding 25 and a few more than 500. This is one of the important reasons for the widespread use of limestone for water-bound macadam roads.

Ballast. Crushed limestone has been widely used for railroad ballast in the past but has been decreasing in favor in recent years. One reason is that the heavy rolling stock demands a rock of high crushing strength and limestone in this respect does not compare favorably with many of the siliceous rocks. Another reason given is that the binding quality is too great. The expense of removing limestone ballast to replace ties is high as compared with other varieties of rock. This binding power, on the other hand, increases the value of limestone as ballast in places where it need not be disturbed.

Aviation Fields. A new use for crushed limestone that is just being developed is for covering portions of aviation landing fields. White limestone is one of the best materials for this purpose because of its visibility and its lasting qualities. In one field where crushed limestone had been spread, aviators found it was so easy to see the proper place to land that it was thought that the limestone possessed luminescent properties and the company furnishing the stone so advertised their product. Actually the stone was only ordinary white limestone. Already considerable limestone has been used at air ports and it appears that this use may furnish an important market in the future. Most of the limestones of the State are suitable for this use, although naturally some are superior to others. It is probable that tests will be devised to determine the best ones, just as the State Highway Depart-

ment investigates the white paints that can best be seen on the highways.

Concrete. A large amount of limestone is used as aggregate in concrete structures of all kinds. Many different materials have been used for this purpose such as gravel, cinders, trap rock, blast furnace slag, limestone, etc. and a great deal of research work has been done by the U. S. Bureau of Standards and other organizations to determine the type of aggregate giving the best results. All of these investigations have shown that limestone is one of the very best. Of course, the limestone must be of good quality and devoid of clay which, as described under weathering, is detrimental under certain conditions.

Limestones are especially good for concrete aggregates because they tend to break in angular fragments and afford much surface for the adherence of the cement. For most uses a large percentage of dust is regarded as objectionable. The specifications vary in different cases as to size of particles, freedom from dust and clay, etc.

The Bureau of Standards* has found that concrete in which limestone was used as an aggregate showed greater fire resistive properties than when other materials were used. This was rather surprising as it is well known that the limestone loses its CO_2 and becomes CaO when a temperature of 900°C is reached. The explanations offered are that part of the heat is absorbed in the chemical reaction and also that after some quick lime is formed in the outer portions the inward transfer of heat is increasingly slow because of the poor conductivity of the lime.

PULVERIZED STONE

Ground or pulverized limestone has come into much more general use in recent years for a number of different purposes. It is a question where the line should be drawn between crushed stone and ground or pulverized stone. As yet no arbitrary size of the fragments has been decided upon to mark the line of separation. Also there has been no agreement as to whether a distinction should be made between ground and pulverized limestone. In the minds of most people, pulverized limestone probably is regarded as finer than ground limestone. The writer believes that it would be helpful to the industry if there could be some agreement upon arbitrary limits for the various designations. It appeals to him that it might be well to classify all sizes in excess of one-fourth inch as crushed stone, from one-fourth to one-tenth inch as ground stone, and all finer as pulverized. The screens for separating the products would be selected as the 4-mesh and 10-mesh, meaning four and ten openings to the inch or 16 and 100 openings per square inch. Of course, the openings in a 4-mesh screen are somewhat less than one-quarter inch in width as some space is required for the thickness of the wire and in the finer screens the proportion of the space taken by the wires increases.

In the ordinary crushing operations considerable of the fine sizes will be produced and this may be separated, sized and collected. Where much attention is given to the making or sale of the finer grades it is usual to find special equipment for the purpose. It is usually regarded that stone is ready for grinding or pulverizing when it has

*A comparison of the heat insulating properties of some of the materials used in fire-resistive construction: U. S. Bureau of Standards, Tech. Paper 130, pp. 26-29, Washington, 1928.

been reduced by primary crushing to about 1½ inches in diameter, although in some swing-hammer mills the process of crushing and pulverizing may be a single stage.

If preceded by initial crushing, the further reduction is carried on by the employment of many different kinds of mills such as swing-hammer mills, ball mills, ball-and-ring mills, ball-and-pusher mills, etc. All of them are capable of producing almost any degree of fineness desired. The pulverizing may be accomplished with the product wet or dry. If the material has first been dried it is common to collect the material by a process of air separation.

For some purposes the kind of limestone is of little consequence as only an inert fine material is demanded. In other cases, the particular chemical composition is essential.

Fillers. In recent years there has been an increasing demand for inert mineral fillers in the manufacture of various products. W. M. Weigel* has made some investigations for the Bureau of Mines and quoted paragraphs are from his articles.

"Mineral fillers, as the term is used in this paper, are those non-metallic minerals that, after being pulverized, are used in the preparation of various manufactured articles. Kaolin, whiting (applied broadly to chalk and to ground limestone and marble), silica, ochre, mica, talc, barite, slate flour, graphite, and diatomaceous earth are the chief mineral fillers. Different forms of some of these minerals are employed; as, for example, silica may be ground quartz, or pumice, or tripoli, the fine rounded grains resulting from the weathering of chert.

"Each mineral has properties that make it suitable for certain uses. These properties are color, specific gravity, the nature of the surface, and the shape, and, probably of greatest importance, the size of the particles. Most fillers are used essentially as inert substances to occupy space, fill voids, or impart color, but in some lines of manufacture they have an important but not easily understood effect on the physical properties of the finished article. For example, ground barite and marble, aside from their specific gravity, have particles that are much alike in appearance and shape, and yet the properties they impart to a rubber compound are quite different. Of chief importance in the comparison of fillers from the same mineral, and to a less degree of fillers from different minerals, are the average particle size, the variation in size from maximum to minimum, and the proportionate amounts of the different sizes; the shape of the grains ranks second and applies more especially to the comparison of fillers from different minerals.

"Although fillers are used in a great number of industries, the bulk of the material goes into the following products: Paper, wallpaper, prepared roofings, rubber, paint, linoleum, oilcloth, foundry facing, plastic cements, oxychloride cement, artificial stone, polishes and scouring compounds, matches, dressing and dusting powders, various textile products, such as window shade cloth, and phonograph records."

Pulverized limestone or marble, commonly called whiting, (although correctly whiting is ground chalk) are probably used in larger quanti-

*Wiegel, W. M., Size and character of grains on nonmetallic mineral fillers: U. S. Bureau of Mines, Tech. Paper 296, 44 pp., 1924.

ties than any of the other fillers. For this purpose waste materials are commonly employed, especially waste marble, but the increasing demand and high transportation rates are resulting in the production of this material from white limestones in various parts of the country.

In every case it is necessary to grind the material very fine in either roller, tube, ball, or hammer mills. Some specifications call for 98 or 99 per cent fine enough to pass through 200-mesh and others 300-mesh screens. The finest material is obtained by water flotation, or air separation.

Probably the most extensive use of limestone filler is in asphalt paving mixtures where its presence toughens the mix and renders it less susceptible to temperature changes. It is according to Wiegel* also "used in rubber, paint, a few grades of paper, linoleum, oilcloth, shoe polish, putty, tooth powder, roofing and artificial stone. For use in rubber, linoleum and paint the alkalinity should be very low. Freedom from grit is required for nearly all uses. A pure white color is essential for use in paint, shoe polish, and similar products. Low oil absorption is of greatest importance in the paint and linoleum industries. There are many grades of whiting, ranging from the amorphous material produced from true chalk to the highly crystalline material from marble. Different whitings possess different physical properties, often when quite similar in chemical composition, fineness, and appearance. Such differences are often difficult to understand. For example, of two whitings of similar chemical composition, grain size, and general appearance, one will make good putty while the other may not."

Several limestone companies in the State have produced whiting as one of their products particularly some of the York County operators. Only one company is solely producing whiting. It is located in Montgomery County and is described in the chapter devoted to that county. It is operating an old marble quarry and obtains all its stone by underground mining.

Stone suitable for whiting is found in Pennsylvania mainly in Montgomery, Chester, Lancaster, and York counties, although some ledges in the Cambro-Ordovician formations of the Great Valley and the central portion of the State are found satisfactory. No careful intelligent search for stone for this purpose has yet been made and it seems that this is a branch of the limestone industry that might well be extended. In most cases it probably would be advisable for a prospective producer to plan on making different products so that any of the beds containing too much iron or other coloring constituents to be serviceable for whiting might be utilized in other ways. Even the purest beds near the surface may be stained by percolating surficial waters to an extent that would condemn their use for filler.

Paint. Pulverized limestone, chalk, hydrated, and air-slaked lime are used in the manufacture of paint. The chief essentials are extreme fineness of the product and desirable color. The presence of magnesia seems to improve the spreading qualities of the paint.

Slaked lime is the pigment of whitewash that in earlier times was more extensively used as a paint both on interior and exterior sur-

*Wiegel, W. M., Nonmetallic mineral filler industry: Trans. Amer. Inst. Min. and Met. Eng., vol. 68, p. 595, 1923.

faces than at present. It is also mixed with other ingredients in the manufacture of more elaborate paints.

Calcium carbonate as natural chalk, pulverized limestone or marble, or the chemically precipitated variety is used in several kinds of paint as an "extender" or harmless adulterant to increase the volume of the paint. In this case cheapness determines its use. It may have a positive value as do several of the so-called "extenders" but this has not been proved.

Glass and porcelain manufacture. Calcium oxide is a necessary constituent in the manufacture of most glass. It is commonly introduced in the form of ground limestone but in some plants quicklime is used and in others hydrated lime. Cost, availability, and present practice are the principal determining factors although the kind of glass manufactured may require a particular form of calcium oxide. There is also considerable variation in the permissible impurities. High magnesium material may be used, and in some kinds of optical glass, is desirable. The presence of magnesia renders the mixture more difficult to melt. The silica content should be less than 4 per cent for the best glass but may run as high as 17 per cent for some varieties. Alumina should be less than 3 per cent, except for some glass in which 5 per cent is allowed. Sulphuric and phosphoric anhydrides should be less than 1 per cent. Iron is objectionable because of its coloring properties. For the best glass no more than 0.2 per cent is permissible, but for the poorer qualities 0.8 per cent is allowed.

Limestone, besides being essential in the manufacture of most kinds of glass by forming one of the necessary constituents, is also serviceable in that it acts as a flux and facilitates the liquefaction of the mix. It has been argued that its use is primarily as a flux, a point of view not accepted by the writer. Some ground or pulverized limestone shipped to glass factories has been billed as fluxing stone and under such a classification took a lower freight rate.

Formerly the limestone used by the glass manufacturers was ground very fine, but modern practice of window and plate glass manufacturers is to use material that passes through a 6-mesh screen but is retained on a 10-mesh screen.

Limestone and lime are used as fluxes in the manufacture of pottery and porcelain. Ground limestone is mainly employed, principally because of the lesser cost, but lime is necessary in some cases. Magnesian material is desirable as the points of vitrification and fusion are farther apart when magnesia is present although high calcium limestone and lime are also used. For glazes a low magnesian content is better. Due to the relatively small amount of calcareous matter required the impurities present can usually be ignored.

Rock dusting of mines. When the U. S. Bureau of Mines was established in 1910, one of the first problems assigned for study was the explosibility of coal dust such as results from the blasting and breaking of coal in bituminous mines. At that time there was still doubt in the minds of some as to whether coal dust was explosive. Ever since that time these investigations have been in progress and a large amount of literature on the subject has been published.

It has now been definitely established that bituminous coal dust

accumulating on mine timbers and in entries has been responsible for much of the damage in mine explosions. It has further been demonstrated that the mixture of some inert pulverized material with the coal dust renders it impossible to propagate an explosion. A number of inert substances have been used, such as limestone, gypsum, shale, clay, adobe, etc., but there is fairly general agreement that limestone dust is best because it is free from combustible material and from grit that might be injurious if breathed by the miners and being white it is possible for the mine officials to determine the approximate amount present in the mixture of coal and applied rock dust. In addition, the white color increases the visibility in the passage ways and thus renders them safer for the men passing through them.

Rice and Greenwald[1] say "several sizes of rock dust have been tested in the Experimental mine: (a) That passing through 100-mesh, now termed "pulverized" dust, of which about 95 per cent or more passes through a 200 mesh sieve; and (b) rock dust through 20-mesh, of which 27 to 40 per cent passes through a 200-mesh sieve. When the coarser size was first tried[2] it was expected that a much larger proportion would be required in a mixture of coal dust to prevent propagation of an explosion. However, tests (though few in number) indicated that the additional requirement was not more than 5 per cent of the total mixture. As the rock-dusting of commercial coal mines had not been started in this country at that time (1916) and standard specifications had not been drafted, the difference was considered of minor importance; 20-mesh shale dust has continued to be used in the Experimental mine except for special testing.

"When rock-dusting was taken up extensively in this country in 1924, mine operators asked for specifications. Accordingly, the bureau issued tentative specifications for rock-dusting and rock dust.[3] It was recommended that all dust should pass a 20-mesh sieve and 50 per cent should pass a 200-mesh sieve. This recommendation was later incorporated in the Recommended Standard American Practice for Rock-Dusting Coal Mines, approved December 30, 1925, by the American Engineering Standards Committee, except that the proportion passing a 200-mesh sieve was specified as 50 per cent or more.

"The rock dust on the market today is intermediate in size between the pulverized and 20-mesh used at the mine, and it was decided that in certain research tests shale dust having 70 per cent through 200-mesh should be used. Ninety-eight per cent of this dust passed 48-mesh, and it was commonly called 48-mesh dust. Comparative tests were made to determine the relation of its effectiveness to that of 20-mesh and pulverized shale. The few tests made indicated that both pulverized and 48-mesh dust were more effective than 20-mesh rock dust, and the difference was about the same as would be obtained using 5 per cent more of the coarser dust in a mixture. However, these tests do not settle the matter satisfactorily because the 20-mesh dust used did not fulfill the rock-dusting specifications. It is proposed

[1] Rice, G. S. and Greenwald, H. P., Coal-dust explosibility factors indicated by experimental mine investigations; 1911 to 1929: U. S. Bureau of Mines, Tech. Paper 464, 45 pp., Washington, 1929.

[2] Rice, G. S., Jones, L. M., Egy, W. L., and Greenwald, H. P., Coal-dust explosion tests in the experimental mine: U. S. Bureau of Mines, Bull. 167, pp. 423-426, 1922.

[3] Rice, G. S., Paul, J. W., and Sayers, R. R., Tentative specifications for rockdusting to prevent coal-dust explosions in mines: U. S. Bureau of Mines, Rept. of Investigations, Serial 2606, 6 pp., 1924.

in the near future to make a series of tests to compare rock dusts having 50, 70, and 95 per cent through 200-mesh.

"The foregoing concerns only the ability of rock dust to prevent propagation of a coal-dust explosion when mixed with the coal dust as a cloud in air. It does not determine the size of dust particles that may be best distributed from a rock-dusting machine, which is purely a mechanical problem. Certain advantages accompany the use of coarser dust. Coarser dust will dislodge coal dust more easily when thrown on the ribs; it does not pack together as does the finer dust, and rapid haulage does not fan it into the air to the same extent."

The Bureau of Mines recommends that the rock dust should always be at least 65 per cent of the rock and coal-dust mixture. When it falls below this amount additional rock dusting should be done.

In practice most of the dust is distributed by mechanical appliances although in some cases by hand. To date more coal mines in Pennsylvania were employing rock dusting than in any other State. In 1927 there were 129 mines in the State where this practice was in effect.

Rock dusting has been of material assistance to the limestone industry of the State as practically all if not all of the Pennsylvania mines using this safety measure have used domestic pulverized limestone. It is probable that some has been shipped to adjoining States. As the practice is extended more and more, there will be an increased demand which the limestone operators can readily satisfy. As the bituminous coal mines are all in the central and western portions of the State, naturally the limestone dust is mainly supplied by quarries in those sections. Many of the larger limestone operations are now furnishing rock dust and others can readily do so.

Agricultural fertilizer. The value of lime and limestone to the agricultural industry has long been recognized and for centuries farmers have fertilized the soil by the application of limestone, chalk, oyster and clam shells, and calcareous marl, either in the raw or in the calcined condition. Such material produces the following effects: (a) It will neutralize active acid. (b) It creates a condition in the soil favorable for the growth of many valuable crops. (c) Its presence favors the growth of many of the legumes and promotes the use of the nitrogen of the air by those plants. (d) It improves the type of decay of organic matter in the soil with the formation of humus. (e) It supplies nutrients in the form of calcium and magnesium for the use of plants. (f) It may improve the tilth of the soil. (g) It improves the sanitary condition of the soil.*

In an elaborate chart issued by the National Lime Association a number of other specific cases are given showing the agricultural value of lime in crop production and protection, animal growth and protection, and the protection and preservation of animal products.

Recent investigations have shown that most plants require both calcium and magnesium, which means that magnesian dolomitic limestone is preferable as fertilizer to the pure calcareous variety. The calcium is built up as an essential constituent of the stems, leaves and roots whereas the magnesium is stored up finally, mainly in the stems. Magnesium also constitutes an important part of chlorophyll,

*Fippin, E. O., The use of lime on the soil: N. Y. State College of Agri. at Cornell Univ., Lesson 148, Ithaca, 1919.

the green coloring matter of plants. The relative amounts of calcium and magnesium best suited for the fertilizing use has not been definitely determined but probably depends upon the kinds of plants. The neutralizing ability of dolomitic limestone is greater than that of pure calcium limestone but the high-magnesian stone will produce only a faint degree of soil alkalinity, probably explained by the greater tendency of the magnesium to enter into chemical combination with some of the silicates of the soil.

The improvement of the tilth, or friable condition of the soil, is brought about by the addition of quick lime which tends to flocculate the soil particles and render a heavy clayey soil much more porous and granular and a sandy soil less porous. A clay soil will drain much better if lime is added, and the roots of the plants can more easily obtain the necessary nourishment.

With the exception of the last mentioned uses, all of the benefits of soil fertilization can be obtained by the addition of ground quicklime, hydrated lime, air-slaked lime, or ground limestone. There is great divergence of opinion in regard to the relative merits of the different materials but the principal factor is undoubtedly the cost per unit of calcium oxide. Viewed in this manner, 500 pounds of quicklime, the amount commonly specified for one acre, is the equivalent of 950 pounds of hydrated lime or 1250 pounds of air-slaked lime or ground limestone. The trade name for ground limestone is ag-stone. The action of the ground limestone is slower and the effect will extend over a longer period of years than if lime is used. Oyster shells and calcareous marl have long been used in the soils, but the use of pulverized limestone is a rather recent application and the annual production is rapidly increasing. There is considerable difference of opinion in regard to the most effective state of fineness of ground limestone. In some cases a product that will pass through a 100-mesh screen is guaranteed but more general practice calls for 15 to 18 per cent from 10 to 50 mesh size, 10 to 12 per cent between 50 and 100-mesh size, and 70 to 75 per cent finer than 100-mesh. Naturally the coarser particles may remain in the soil several years before they are entirely decomposed.

Probably far more quarries in the State have been worked to obtain stone for agricultural lime than for any other use. At an early day almost every farmer who had any limestone on his property quarried stone and burned it for lime. This custom still prevails, but from year to year the smaller operations cease and there is less liming of the soils. In certain places all of the lime now used is purchased from the large lime operators. It remains to be seen whether there will continue to be greater substitution of ag-stone for lime for agricultural use and what effect this will have with respect to the small local limestone quarries.

Animal food. Finely crushed or granulated limestone has been used as chicken grit, although other kinds of stone are also utilized for this purpose. When so used part of the calcium carbonate undoubtedly passes into solution and supplies the body with part of the lime needed, although the principal use may be for grinding the food particles.

In recent years, experiments have been conducted to determine the

value of ground limestone when fed to cattle. Some results obtained are described by C. W. McCampbell* as follows:

"Calcium serves several important functions in the animal body. It helps to build up and maintain the bone tissue. Analyses of bones show 51 per cent calcium phosphate, 11 per cent calcium carbonate, and 5 per cent other minerals. In other words, 62 per cent of bone is made up of calcium combinations. Calcium is also necessary to insure proper functioning of the nervous system. It may also act as a neutralizer in the digestive tract. So we see that calcium plays an important part in maintaining the health and thrift of livestock, and if sufficient calcium is not present in the rations we are feeding them, calcium should be added to the ration feed. The question naturally arises as to the form in which it can be fed. The Kansas Agricultural Experiment Station ran a series of tests for the purpose of determining, if possible, the most satisfactory form in which calcium could be added to a livestock ration, both from the standpoint of efficiency and economy. These tests pointed to finely ground high calcium content limestone as the most satisfactory.

"For cattle we recommend the use of one-tenth of a pound per day of ground limestone regardless of age ......"

"There is a considerable variation in the feeding value of the ground limestone offered for sale by different firms. A satisfactory product should contain at least 95 per cent calcium carbonate, no fluorine, and very little magnesium. It must be ground very fine for livestock feeding purposes—almost as fine as wheat flour. Ordinary fertilizer lime is not ground fine enough for livestock feeding purposes."

FLUX

Limestone is essential as a fluxing material in the manufacture of iron and steel, and also in non-ferrous metallurgical operations. Between one-third and one-half of all the limestone produced in the United States is used in this way. The purpose of the limestone is to make a fusible slag of the impurities of the iron ore, mainly silica and alumina, and the ash of the coke. Ordinarily about half a ton of limestone is used for a ton of pig iron.

The suitability of a limestone for use as flux depends almost entirely upon its chemical composition although the physical condition is of importance. For example, there must not be much dust and this fact eliminates marl from furnace use.

Limestone for flux should be low in silica and alumina, the lower the better. Since the object of the limestone is to remove these impurities the material is obviously less efficient if it contains much of either of these two substances. However, they are both present in practically all limestone and the amount that will be tolerated depends upon availability and cost of the stone. Whereas one company favorably located with respect to good fluxing limestone will only accept stone containing less than 3 or 4 per cent of alumina and silica, another company, less advantageously situated, may find it cheaper to use stone with double the amount of impurities. In general, purer stone is required for the open hearth process than for the blast furnace.

*McCampbell C. W.: Rock Products, vol. 34, p. 63, 1931.

Description of Limestone in its Various Forms, Uses, Values, Manner of Shipment and Average Loadings

Prepared by the American Lime & Stone Co., Bellefonte, 1929.

Item No.	Commodity	Size	Chief Uses	Manner of shipment	Average values net ton	Average loading per car net tons
1	Ground	All through a 20 mesh screen and 97% through 100	Mine dust Agricultural purposes Base for dye Asphalt filler	In box cars Chiefly in bags also in bulk	In bags $5.00 In bulk 3.50	25
2	Ground	All through a 20 mesh screen and 85% through 100	Agricultural purposes Asphalt filler	In box cars Chiefly in bags also in bulk	In bags $4.50 In bulk 3.00	25
3	Glass house	All through a 6 mesh screen	Plate glass Window glass	In box cars In bulk only	$1.75	51
4	Glass house	All through an 8 mesh screen	Plate glass Window glass	In box cars In bulk only	$1.75	51
5	Screenings	All through ½" screen	Building Concrete Highways	In open cars	75 cents	55
6	Screenings dustless	All through ½" and retained on ⅛" screen	Building Concrete Highways	In open cars	$1.05	55
7	Crushed	⅝ to 1 inches	Building Concrete Highways	In open cars	$1.05	55
8	Crushed	⅝ to 1¼ inches	Building Concrete Highways	In open cars	$1.05	55
9	Crushed	⅝ to 2¾ inches	Concrete Highways	In open cars	$1.00	55
10	Crushed	1¼ to 2¾ inches	Concrete Highways	In open cars	$1.00	55
11	Crushed	1¼ to 3½ inches	Concrete Highways	In open cars	$1.00	55
12	Fluxing (foundry)	2½ inches	Cupola fluxing	In open cars	$1.00	55
13	Fluxing (furnace)	1¼ to 5 inches	Blast furnace fluxing	In open cars	$1.25	55
14	Fluxing (one man size)	Over 5 inches	Open hearth furnace fluxing	In open cars	$1.25	55

"Referring[1] to limestone and dolomite as blast furnace materials, there is a difference of opinion among furnace men to their relative value as fluxes. Some hold that limestone is the better, while others maintain that dolomite gives as good, if not better results, their opinion usually being influenced by their training and by the extent of their experience with these materials. The presence of magnesium in limestone in small amounts has little effect, but as the content increases, it may lower the fusion point of the resultant slag by the formation of double salts. A high percentage (over 3 per cent) of magnesia in blast furnace slag renders it undesirable for cement, but for concrete, ballast, etc., it is desirable as it makes the slag harder. Aside from this objection, not one of much weight, the factor that governs the choice between limestone and dolomite is the cost per ton of available base."

On account of the wide interest among limestone operators of the use and requirements of limestone for fluxing purposes, extensive quotations from a recent report[2] of the Bureau of Mines are given.

"Enormous quantities of limestone are employed in modern metallurgy, particularly for fluxing. Approximately 24,000,000 tons were so used in the United States in 1926, chiefly in the smelting of iron ores in the blast furnace."

"Most limestone producers have little knowledge of the way in which their stone is used in metallurgy. The maximum content of silica, alumina, sulphur, and possibly magnesium and the minimum content of calcium carbonate may be arbitrarily fixed for the guidance of the producer; but aside from these requirements little information is available to producers on how their stone is used, the office it performs in smelting, or the effects of impurities. More complete knowledge of utilization would enable limestone operators to solve their production problems more intelligently."

"The chief impurities in most iron ores are silica and alumina, and the addition of a basic flux is necessary to form a slag. If iron ore were reduced without flux, the siliceous and argillaceous gangue would unite with the iron oxides to form double silicates of iron and alumina, which would involve a heavy loss of iron. With the addition of limestone, the silica and alumina have a stronger affinity for the lime and magnesia than they have for the iron, and in consequence double silicates of lime and alumina or magnesia and alumina are formed—compounds which contain very little iron. Just as an acid and a base react to form a salt, so the siliceous impurities of the ore react with the basic flux to form a slag which corresponds to the salt of wet chemistry. Lime is infusible at the temperature of a blast furnace, but when it combines with the silica and alumina of the furnace charge it forms a liquid slag which floats on the molten iron.

"At the fusion zone approximately 15 per cent of the original iron exists as FeO, and this must be reduced in the lower part of the furnace. With insufficient flux a black slag containing iron is likely to be made during the reduction process. It is true, however, that a normal

[1] Camp, J. M. and Francis, C. B., The making, shaping and treating of steel: Second edition, p. 118, Pittsburgh, 1920.

[2] Bowles, Oliver, Metallurgical limestone: U. S. Bureau of Mines, Bull. 299, 40 pp., Washington, 1929.

supply of lime will not in itself prevent loss of iron in the slag; other conditions must also be correct.

"Coke is used as blast-furnace fuel, and when it burns varying amounts of ash are formed. The ash is composed largely of silica and alumina, which, like the similar impurities in the ore, must be removed. Therefore the formation of a slag with the ash is a secondary function of the limestone flux. The slag should pick up the coke ash in the combustion zone, for it is desirable to remove the ash which forms on the coke lumps in order that the coke surface shall be clean. As the combustion zone is the seat of life in a furnace, it is not only necessary to remove the ash but also to produce a slag which will pass freely through this part of the furnace. An improper slag adheres to the coke and is chilled by the blast. This results in a sluggish tuyère, and tuyère action must be carefully controlled by the furnace operator. The slag should have a melting point below the average tuyère temperature and should be fluid enough to pour out readily through the cinder notch.

"Another purpose of the flux is to remove sulphur from the metal. Most of the sulphur enters the furnace in the coke, but there is a transfer of sulphur from the coke to the sponge iron. Metal, even when it has reached the bosh of the blast furnace, often contains twice as much sulphur as is permissible in the pig iron. Proper additions of flux with necessary temperature adjustments reduce the amount to specified limits.

"In some localities, iron ores are associated with sufficient lime carbonate to be self-fluxing. Ores are said to be self-fluxing when the sum of the calcium and magnesium oxides is approximately equal to the sum of the silica and alumina. Such ores occur in the iron district of Birmingham, Ala. They smelt very readily, as the constituents are intimately mixed.

"Some ores are basic in character and require an acid flux, the most common of which is silica.

"When subjected to the heat of the furnace, the limestone in the charge is first converted to CaO (lime) and CO_2 (carbon dioxide.) The lime reacts with the impurities to form slag. Precalcined lime is said to combine more readily with the impurities than the lime formed by calcination in the furnace, but the extra cost of precalcination probably more than offsets this advantage. Calcination of $CaCO_3$ in the furnace is more economical than precalcination, because usually there is enough available heat in the upper part of the furnace, and the heat used for calcination would otherwise be lost as sensible heat in the waste gases.

"Alumina may be regarded either as an acid or a base; it will combine with silica to form aluminum silicate, thus performing the office of a base, or with lime to form calcium aluminate, acting in the capacity of an acid. In ordinary blast-furnace practice silica and alumina (SiO_2 and Al_2O_3) are regarded as acids and the lime and magnesia (CaO and MgO) as bases. Feild and Royster* found that, in general, the effect of increasing the Al_2O_3 content of slags is to increase viscosity and melting temperatures, although under some conditions this may not be true. In general, therefore, the presence

*Feild, A. L., and Royster, P. H., Slag viscosity tables for blast-furnace work; Bureau of Mines, Tech. Paper 187, 1918, 20 pp.; Trans. Am. Inst. Min. Eng., vol. 58, 1918, p. 654.

of excessive alumina in either flux or ore not only requires a correspondingly large amount of calcium or magnesium to neutralize it but also demands additional heat units to give the resulting slag the desired fluidity. On this account the clay content of fluxing stone should be kept at a minimum. Recent work by Joseph[1] indicates, however, that furnaces can be operated successfully with high-alumina slags.

"Definite data on lime-alumina-silica compounds in the liquid phase of slags are not now available. It is generally assumed, however, that for efficient sulphur removal an excess of limestone over that required to satisfy the demands of the silica and alumina should be added."

"The majority (p. 9) of blast furnaces employ about 900 pounds of flux for each long ton of pig iron produced. The amount of flux required varies with the amount and nature of the impurities in the ore and in the stone itself. The foreign elements in fluxing stone are usually the same as those in the ore—namely, silica and alumina—and to remove them the flux is added. It should be emphasized that impurities in the limestone are doubly detrimental. (1) Their presence reduces the percentage of lime and magnesia in the stone, and (2) they require a certain share of the lime and magnesia to flux them off, as the flux must neutralize its own impurities as well as those of the ore."

"Other impurities (p. 11) in the stone are sulphur and phosphorus, but usually they are present in amounts so small as to be negligible. A sulphur content of less than 0.1 per cent does no harm, and it is unusual to find more than this amount in commercial limestone. Hall[2] states that for 110 analyses of Pennsylvania limestones given in State College reports of 1899 and 1900 the average sulphur content was only 0.08 per cent, while in 163 analyses sulphur was ignored because there was so small an amount. Phosphorus is usually deleterious only where the flux is used in the manufacture of Bessemer iron. For this purpose the phosphorus content should be as low as possible and should not exceed 0.01 per cent. For other grades of iron the phosphorus content may reach 0.1 per cent without harmful results, but a content as high as this is exceedingly rare."

"The effect (p. 11) of magnesia in fluxing stone is an unsettled question. Some blast-furnace men are opposed to its use while others use it successfully. Dolomite is widely used as a blast furnace flux in England. If it is assumed that all the magnesia united with silica to form $MgSiO_3$ and all the lime unites with silica to form $CaSiO_3$, it would appear that magnesia is the better fluxing agent, for 1 pound of MgO will convert 1.51 pounds of SiO_2 into $MgSiO_3$. It is probably on this basis that Forsythe[3] makes the statement, 'MgO has a fluxing power 1.4 times that of CaO.' This is not a safe assumption, however, for other compounds are also formed, such as disalcium and tricalcium silicates, also calcium and magnesium aluminates. Much is still to be learned concerning the proportion of such compounds formed under varying conditions and the effect on slag viscosity of the various possible compounds."

"There seems (p. 13) to be much difference of opinion as to the

[1] Joseph, T. L., Production of high-alumina slags in the blast furnace: U. S. Bureau of Mines, Tech. Paper 425, p. 31, 1928.

[2] Hall, R. D., Discussion: Trans. Am. Inst. Min. Eng., vol. 63, p. 927, 1920.

[3] Forsythe, R., Blast furnace and the manufacture of pig iron: 1922, p. 160.

effect of magnesia on the viscosity of slags. In the published results of a number of tests covering the smelting of various metals the statement is made that magnesia tends to make the slag ropy and viscous; in fact, it is mentioned so frequently by practical operators that it seems to be established as a fact. This conclusion, however, would appear to conflict with theory. It is a well-established principle that a silicate with more than one base fuses at a temperature lower than a one-base silicate."

"As a rule, (p. 14) high-calcium fluxes are preferred, but the difference in action between the high-calcium and the dolomitic fluxes is so small that usually the choice is governed by other factors, such as availability, cost or percentage of impurities.

"It has been claimed that in cupola furnaces dolomite is more effective than high-calcium stone, only about four-fifths as much dolomite as high-calcium stone on a tonnage basis being required to do the same work."

"Where crushed (p. 14) or granulated slag is used for concrete aggregate or road building as a substitute for crushed stone, the magnesia content is not generally regarded as important. However, in a recent communication from a company producing very large quantities of fluxing stone, the statement is made that some blast-furnace operators are requesting stone with 7 to 10 per cent of magnesia because the resulting slag is more desirable for road making. The advantage is probably due to the decreased slaking effect in the high-magnesia slags. Slag is now used extensively for the manufacture of Portland cement. For this the flux must provide a slag having a magnesia content within the fairly narrow limits demanded by cement specifications."

"Fluxing stone (p. 16) is used in a great variety of sizes. At some furnaces the crusher run is used without screening. Usually the fines below ½ inch are taken out, because they tend to retard the draft and because they frequently contain more impurities than the lump stone, as sand and clay segregate in the fines. In modern quarry practice, and particularly in underground mining, less impurity is mixed with the stone than during former years under cruder practice; therefore, on the basis of purity, fine materials may not be detrimental. A common range in size is 4½ inches to ½ inch, although larger sizes are often used."

"The open-hearth process (p. 17) of making steel consists of melting pig iron and steel or iron scrap and boiling the mixture, generally with the addition of some very pure lump iron ore, until the carbon is reduced to the desired amount. A flux is added to the charge in the furnace mainly for the removal of phosphorus and sulphur. For a phosphorus content in pig iron not exceeding 0.25 per cent, additions of 6 to 12 per cent of limestone are considered good practice. When a pig iron with a higher phosphorus content is used, as much as 17 per cent of limestone may be charged. The phosphorus is oxidized to phosphoric acid, which unites with the lime to form calcium phosphate. The ability of a slag to take up phosphorus depends both on basicity and fluidity."

"The maximum (p. 29) permissible limit of sulphur in flux is 0.5 per cent. The upper limit of phosphorus for Bessemer iron is placed at 0.01 per cent and for non-Bessemer iron at 0.1 per cent. In most

commercial limestones the sulphur and phosphorus content are so small that they may be disregarded. Sulphur is more common than phosphorus, for sulphides such as pyrite and marcasite are frequently found in limestone. Due to their yellow color and metallic luster, the sulphides are usually easily detected.

"The most common impurities and those that demand most consideration are silica and alumina. For blast-furnace use, no set rules are given as to the permissible percentage of these impurities, but for average practice it is desirable to keep the total impurity under 5 per cent. If a low-silica ore is being smelted a flux with considerably more than 5 per cent impurity may be used, provided it is low priced. On the other hand, a siliceous ore may demand a flux having less than 5 per cent impurity. The producer should familiarize himself with the demands of individual furnaces within his market area. For basic open-hearth flux the silica content should not exceed 1 per cent or the alumina content 1.5 per cent."

CEMENT

Portland cement. The principal cement of the world is named "Portland" because of its resemblance after hardening to the Portland limestone of England, a stone extensively quarried and widely used. Pennsylvania has been the principal Portland cement producing State since the beginning of the industry in this country and in recent years probably half of the limestone quarried in the State has been used in this way.

In the manufacture of Portland cement, limestone of various kinds is used either alone or admixed with other materials. Argillaceous limestone in the Lehigh district of Lehigh, Northampton, and Berks counties has approximately the correct chemical composition for the manufacture of Portland cement; elsewhere in Pennsylvania it is necessary to mix other material with the limestone to obtain the proper proportions of the requisite ingredients. The manufacturers attempt to secure a uniform composition of about 75 per cent $CaCO_3$, 12 to 15 per cent SiO_2, and the balance Al_2O_3 and Fe_2O_3. There is almost always some $MgCO_3$ present but this is undesirable and should not exceed 5 or 6 per cent. The standard specifications permit a maximum of 5 per cent MgO in the finished cement. For this reason dolomite and high magnesian limestone are unsuitable for Portland cement manufacture but practically all other kinds of limestone, including calcareous marls, oyster shells, fossils, etc. can be utilized if mixed with proper ingredients to secure the necessary elements. Argillaceous limestone is most suitable as it more nearly approaches the proper composition. Alkalies and sulphates are objectionable but they are rarely present in sufficient quantities to warrant consideration.

The cement plants in Berks, Lehigh, and Northampton counties are located in what is called the Lehigh Cement District and all use Jacksonburg argillaceous limestone. Three plants in New Jersey are also included in this district. A few of the companies quarry stone that averages higher in $CaCO_2$ than required for the mix and at times they find it necessary to add a little of the clay stripping. Nearly all, however, have stone deficient in lime and are compelled to bring in high grade limestone. This comes largely from the Lebanon Valley and

contains from 94 to 96 per cent of $CaCO_3$ or occasionally more. The cost of this stone and the transportation charges place a heavy burden on some companies, especially if a large amount is required. At times some companies have bought as much 30 per cent of the stone used. The high grade limestone added by most companies seldom exceeds 20 per cent of the mix and in most cases is much less. Due to variation in composition of the argillaceous limestone the amount of purchased stone varies from day to day.

All the other cement plants of the State make cement by mixing high grade limestone and clay, shale, or blast furnace slag. The Portland cement plants in Lawrence, Butler, and Allegheny counties use the Vanport limestone. The two plants in Allegheny County use furnace slag but the others use shale that is quarried in close proximity to the limestone. The single plant in York County uses local limestone and clay, and the plant in Montgomery County obtains a mix from its quarry in metamorphosed, micaceous limestone.

The details of the different operations are given in the descriptions of the various counties.

The question is often asked whether there are other regions in the State where proper materials might be found for making Portland cement. The writer is of the firm opinion that suitable locations for satisfactory stone can be found in Lancaster, Franklin, Cumberland, Lebanon, and Centre counties, as well as additional sites in the counties where cement is now being made. Plants may possibly be established in a few other counties. No company should start a plant without careful investigation as there are serious geologic problems to be encountered in many sections because of the complicated structures resulting from the great mountain building movements that have affected the entire eastern and central portions of the State.

Any new plant faces a difficult market situation because the existing plants are more than sufficient to supply present as well as future demand so far as it can be foreseen at this time.

Natural cement. Natural cement, also called Rosendale or Roman cement, is made by burning an argillaceous limestone at temperatures of 1000° to 1100°C. The raw material is of variable composition and a larger percentage of magnesium is permissible. The burning seldom reaches the clinkering (fusing) stage. Nevertheless important chemical action takes place and calcium aluminum silicates are formed. The burning process is similar to the burning of lime. The resulting product is ground fine. It differs from Portland cement in that it sets more rapidly but possesses less strength. It is cheaper on account of less attention given to the chemical composition of the material and less care to the burning.

Until 1900 the production of natural cement exceeded that of Portland cement, but since that year there has been an enormous increase in the production of the latter and a slow but steady decrease in the former until now the production of natural and puzzolan cement combined in the United States is less than one per cent of the entire cement production.

Slag or Puzzolan cement. Puzzolan cement was originally made at Pozzuolia near Naples, Italy, by the intimate mixture of volcanic lava and slaked lime. It has also been made in other parts of the world.

The similarity of basic slags of the blast furnace and lavas suggested the use of slag in the same way and at one time the slag cement industry gave promise of reaching considerable proportions and of successfully competing with Portland cement. This condition has not been realized and production has declined in recent years. In some cases slag cement will pass all the necessary tests for Portland cement, but usually it possesses less strength and sets more slowly.

Few processes are involved in the manufacture of puzzolan or slag cement as it is merely an intimate mechanical mixture of slaked lime and slag, ground fine before, during, or after the mixing of the two ingredients.

Slag or puzzolan cement must not be confused with true Portland cement in which blast furnace slag and limestone are mixed in the proper proportions chemically and burned in the ordinary way as described above.

OPEN-HEARTH FURNACE LINING

Bowles states,* "To avoid rapid corrosion of furnace bottoms by slag, basic open-hearth furnaces must be lined with basic material. The sides and roof are usually made of silica brick; the bottom is built up first with two or three courses of fire brick on the steel shell, then two or more courses of magnesite brick, which are stepped up at the sides. Sometimes a course of chrome brick is inserted between the fire brick and magnesite brick. In some furnaces the fire-brick courses are omitted. Occasionally a course of neutral chrome brick is inserted at the line where the magnesite-brick base joins the silica-brick walls.

"The basic bottom is spread directly on the magnesite brick. Most basic bottoms are made of dead-burned grain magnesite, sometimes mixed with hot tar. A binder of 5 to 20 per cent of basic cinder is added. The grain magnesite is fused on in successive layers to build up the front and back walls well above the slag line. Commonly a wash heat of basic slag or roll scale is melted on and allowed to soak into the bottom. Formerly the preference was for Austrian magnesite, but recently equally successful results are reported by operators using California, Washington, and Canadian magnesites.

"The difficulty of obtaining magnesite and its high price during the war period led many operators to substitute burned dolomite for basic bottoms. For this purpose dolomite should contain less than 1 per cent of SiO_2, less than 1.5 per cent of combined Al_2O_3 and Fe_2O_3 at least 35 per cent of $MgCO_3$, and the remainder of $CaCO_3$. Dolomite is inferior to grain magnesite in that it can not readily be made as dense and vitreous as magnesite, and consequently disintegrates and floats. Magnesite must either be imported or shipped from California or Washington, hence it is expensive; dolomite is of common occurrence and is cheap. Many furnace operators who were forced to resort to dolomite for basic linings have voluntarily continued its use. Some operators report satisfactory results for entire linings as well as for patching from the use of burned dolomites prepared in special ways and sold under various trade names. The general practice, however, has been to revert to magnesite, as it became available, for the major part of basic bottoms.

*Bowles, Oliver: Metallurgical Limestone: U. S. Bureau of Mines, Bull. 299, pp. 22-23, Washington, 1929.

"Although burned dolomite is admittedly inferior to grain magnesite, no basic material is so generally suitable for minor repair work; it is readily obtained at low cost, is infusible enough for the purpose, and fusible enough to frit together and form a hard, mechanically strong bottom, which is not readily acted on by the highly ferruginous and calcareous slags. Dolomite, therefore, is very widely used for patching. Small pits or holes in the bottom are repaired after each heat. It is estimated that 40 to 50 pounds of dolomite per ton of steel are needed for repair purposes."

The dolomitic quarries of Montgomery and Chester counties contain satisfactory material and a considerable part of the output goes to steel companies for this purpose. The dolomite used in the steel plants of the western part of the State comes mainly from Martinsburg, West Virginia.

EXTRACTION OF MAGNESIA

The extraction of magnesia from dolomite has become a rather important industry in this State.

For this purpose a stone with from 40 to 45 per cent $MgCO_3$ is used. The silica must also be low, preferably less than 1 per cent. One hundred pounds, in blocks from 8 to 12 inches in diameter (one-man size), mixed with 11 pounds of coke, is calcined in a closed kiln. The CO_2 is drawn into a gas compressor. The burned product is slaked and ground in a pebble mill and then mixed with an excess of water. Into the mixture, CO_2, obtained from the kiln, is forced under pressure. This causes the magnesium hydroxide to pass into solution, leaving $CaCO_3$ mainly with the impurities derived from the stone and the coke as a fine precipitate. By filtering in filter presses the magnesium solution is separated from the precipitate.

The precipitated $CaCO_3$ is suitable for whiting, cement, paint, fertilizer, etc., but due to the expense of drying, it is in most cases discarded. In one plant this residue contains from 92 to 96 per cent $CaCO_3$. The solution from the filter presses carrying a little more than 2 per cent magnesium bicarbonate [$Mg(HCO_3)_2$] is boiled in closed upright boilers, causing the precipitation of hydrated basic carbonate of magnesia. The CO_2 driven off is drawn back into the gas compressors, and the magnesium carbonate and water is conducted into a gravity filter. At this stage, there is a division of the product depending upon the use to which the material is to be put. It may be dried and moulded and put on the market as the hydrated basic carbonate of magnesium or magnesium alba for pharmaceutical uses, for the rubber trade, as a face powder or as a toilet article. It may be calcined to form MgO and sold for pharmaceutical purposes or for the rubber and chemical industries. Most of it, however, while still containing considerable water, is thoroughly mixed with shredded asbestos in the proportion of 85 per cent magnesium carbonate to 15 per cent asbestos, and moulded into bricks or forms for covering steam pipes, etc. It serves as an excellent heat insulator due to the numerous tiny air cavities present between the grains of the magnesium carbonate. The asbestos fibers are also poor heat conductors although their principal use is as a binder to increase the strength of the forms.

A flow sheet, prepared by the Magnesia Association of America, showing the various chemical changes involved in the process is given in the accompanying figure.

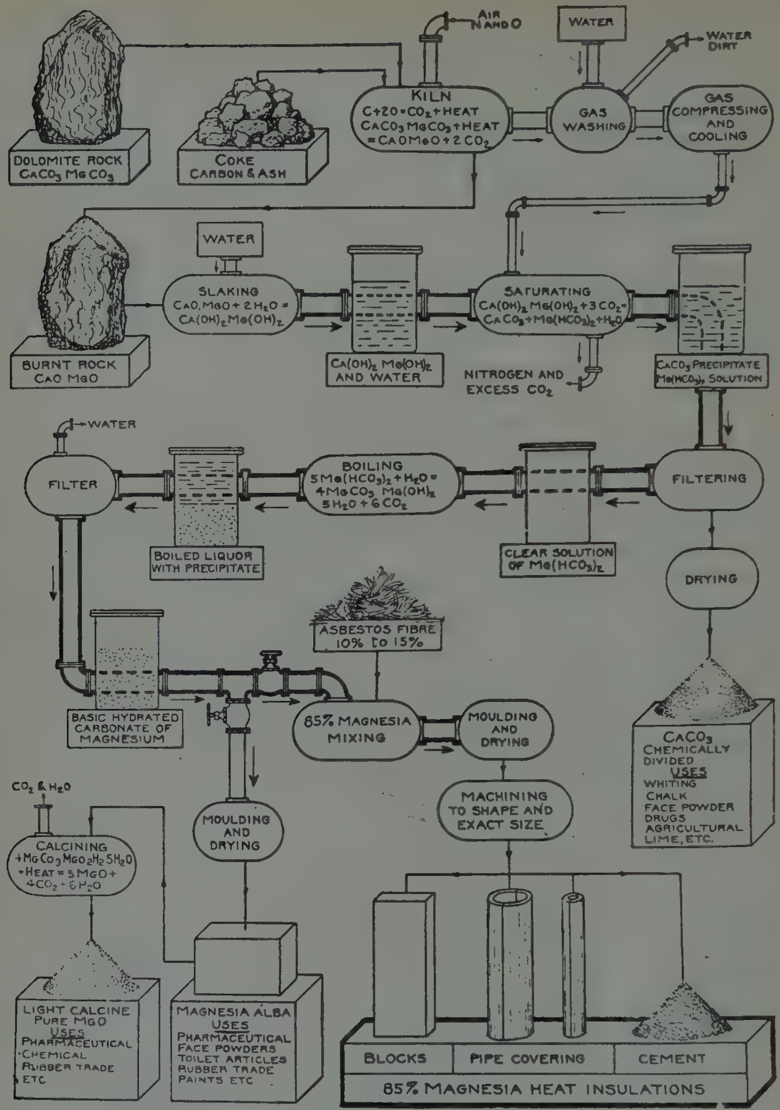


Fig. 1. Flow chart illustrating manufacture of magnesia. The darkened lines show the actual process involved; the lighter lines, by-processes.

The only dolomites of the State that are definitely suitable for the extraction of magnesia are those in Montgomery and Chester counties. Several of the dolomite quarries in the vicinity of Port Kennedy, Plymouth Meeting, Williams and Whitemarsh in Montgomery County, and at Cedar Hollow in Chester County have furnished material to the magnesia plants at Port Kennedy and Ambler in this State and to a plant in Manville, N. J.

At one time a magnesia extraction plant was operated at Mt. Joy in

Lancaster County. For a time the stone was obtained from a quarry a few miles south of the town. It is possible that some other dolomites suitable for this use may be found in Lancaster and York counties.

MINERAL WOOL

In recent years a new product called "mineral wool" has been manufactured from siliceous limestones. Up to the present time no Pennsylvania limestones have been utilized in its production and, so far as known, none from the State have been tested for this purpose. The following quotations from a paper presented at the February 1932 meeting of the American Institute of Mining and Metallurgical Engineers by W. N. Logan, State Geologist of Indiana, presents some interesting data. His description of the manufacturing processes must be omitted.

"What is mineral wool? This question is frequently asked by those unacquainted with its manufacture. The word 'mineral' suggests that it is of mineral origin; the word 'wool' suggests that it is of animal origin; but the only similarities it has to wool are its fibrous character and its white fleecyness. Mineral wool is a fiber produced by melting rock to a glasslike condition and blowing the glass into white, wool-like threads.

"A number of the products fabricated from mineral wool are used for some form of insulation, but mineral wool is adaptable to many other uses. It is used in the manufacture of pipe covering designed to withstand the high temperatures produced in steam pipes. In a similar form of insulation it is used to cover boilers and furnaces. It is used in the fabrication of upholstery tow for sofas and car seats. In acoustics it has many uses, such as acoustifibroblock, which is used in floors to destroy sound and vibration, and acoustic mat, which is used under carpets to destroy sound. In the insulation of houses, loose wool and granulated wool are used beneath attic floors and between the studding in frame buildings to prevent the escape of heat in winter and the entrance of heat in summer. Mineral wool is used also in fabrication of linofelt, which is a quilted form of insulation; in fibrofelt, which is an insulating board; in the fabrication of lith, which is an insulating block; in antifibroblock which is used in insulation and refrigeration; in flexfelt; in loose wool; in pressed block; in heavy oiled wool; in dark oiled block; and for many other purposes.

"The materials used in the manufacture of mineral wool are of two kinds. The first is a rock which contains silt, clay and silica, with smaller amounts of lime and magnesia. The second is a more highly calcareous rock which may carry a small amount of magnesia. The latter is used as flux to assist in the melting of the former. The relative proportion of the alumina-iron-silica content to the lime-magnesia content is normally as fifty to fifty but a considerable range is possible."

"*Hardness.* The hardness of mineral wool rock varies from 1 to 3 in the Moh scale. The softer rock has about the hardness of talc and the harder varieties about the hardness of calcite. The presence of small amounts of silica will greatly increase the hardness of the rock. The larger the amount of clay present, the softer is the rock as a rule.

"*Texture.* Wool rock is normally very fine grained. Coarse particles, although not entirely absent, are rarely present in appreciable amounts. Silt and clay particles are the predominant ones, although in some deposits there occur layers or lenses which contain large crystals or granules of calcite.

"*Structure.* The structure of the wool rock from the Silurian formation is laminated. The laminations may not show in freshly exposed outcrops of the rock but they always develop under conditions of weathering. The wool rock from the Mississippian formations is also distinctly laminated in some outcrops but in the majority of outcrops the apparent stratification is due to change in color of the materials. Joint crevices are present in the wool rock of both the northern and the southern areas. Concretions, vugs and siliceous layers are also present in the rocks from both areas.

"*Specific Gravity.* The specific gravity of wool rock approaches that of varieties of clay. The apparent specific gravity of clay varies from 1.50 to 2.50; the specific gravity of tested samples of wool rock varies from 1.75 to 2.25.

"*Composition.* Analyses of 20 samples of mineral wool rock exhibit an average silica-alumina-iron content of 31.37 per cent and a lime-magnesia content of 31.90 per cent, which is close to a 50:50 ratio. Experiments prove, however, that there may be a considerable range in the percentage of the essential constituents. Three examples are given in Table 1.

Composition of Typical Samples of Wool Rock

	Sample 1	Sample 2	Sample 3
Silica, per cent	23.92	28.08	14.04
Alumina and ferric oxide, per cent	8.00	8.64	3.36
Calcium oxide, per cent	21.48	19.90	42.47
Magnesia, per cent	12.34	12.18	2.46

"*Composition of Mineral Wool.* The analyses of 20 samples of mineral wools exhibit a range in silica content from 22.52 to 49.22 per cent; of alumina-iron content from 5.39 per cent to 15.38 per cent; of lime content from 21.04 to 68.13 per cent; and of magnesia content of from 3.96 to 18.77 per cent. Composition of typical samples are given in Table 2. It is evident, therefore, that a number of compounds enter into the composition of mineral wool and that the percentage of the constituent compounds may vary through rather wide limits.

Composition of Typical Samples of Mineral Wool

	Sample 1	Sample 2	Sample 3
Silica, per cent	36.40	40.81	34.07
Alumina and ferric oxide, per cent	12.16	12.55	11.19
Calcium oxide, per cent	32.67	28.92	44.08
Magnesia, per cent	18.77	17.70	10.57

"The silica of the raw materials exists as free or uncombined silica and as combined silica. As free silica it is in the form of sand and silt particles. The combined silica is in chemical union with aluminum to form clay and to a lesser extent in combination to form grains of mica. Silica in the free state is moderately refractory and not easily

fused. It is more easily fused when in a finely divided state, as in silt. That silica is an essential and an important constituent of mineral wool has been demonstrated by attempts made to produce the product out of rocks containing too low a percentage of the compound and by the analyses of mineral wools in which it is always an important component.

"In the raw materials aluminum is combined with silica to form clay and mica. Alumina is present in wool rock in amounts as large as 15 per cent, but the normal amount is less than that. Alumina is an essential constituent of mineral wool, as is evidenced by the fact that attempts to manufacture mineral wool out of rocks which contained no alumina have met with failure. Alumina probably has its greatest affinity for iron and silica, and while it unites readily with these it is possible for it to form combinations with lime and magnesia.

"Iron is present in wool rock in the form of oxides of iron, hematite and limonite, in the form of sulfides, marcasite and pyrite, and in the form of carbonates of iron.

"During the heating of the wool rock in the cupola the water of crystallization in the limonite is driven off, the carbon dioxide is expelled from the carbonate of iron, and the sulphur of the pyrite and marcasite is converted into sulphur dioxide and expelled. The amount of iron present in wool rock computed as ferric iron ranges from 2 to 6 per cent. One of the important functions of iron is to lower the fusion point. It is especially effective in lowering the melting point of the aluminum silicates, since it readily enters into combination with silica and alumina. Calcium carbonate is present in the raw materials of mineral wool in amounts ranging as high as 45 per cent, but such rocks do not produce good mineral wool. In heating wool rock in the cupola, the carbon dioxide is expelled and the calcium dioxide or lime becomes a part of the 'melt,' or slag. In the slag the lime unites with silica, iron and perhaps alumina. The chief function of the lime is to produce slag at a lower temperature than would be required if no lime were present. However, if a large amount of lime is present, fusion will be prevented, because lime is refractory in amounts too large for proper union with the other constituents.

"Magnesium carbonate is another constituent of mineral wool rock. The amount present is much less than the amount of calcium carbonate. The minimum amount is about 10 per cent and the maximum amount is about 20 per cent. The amount of magnesia in mineral wool ranges from 3 to 12 per cent. Magnesia, like lime, may act as a flux, although it is more refractory than lime and requires a higher temperature to fuse it.

"Titanium oxide is generally present in all rocks containing clay. It is contained in wool rock in amounts which are usually less than 1 per cent. It is very refractory, fusing at high temperatures only, but it is present in such small amounts in wool rock that it has little influence on the manufacture of mineral wool."

It is thought that the Loyalhanna limestone which is well developed in Cambria, Fayette, Indiana, Somerset and Westmoreland counties and discussed in the descriptions of those counties, may be serviceable for this use and for that reason the matter is discussed at this length. The composition is somewhat different from that of the Indiana siliceous limestone which has mainly been used, but it appears that

as yet no one knows just what chemical composition will eventually be found to produce the best quality of mineral wool most economically.

It seems that mineral wool will soon have to compete with a similar product made as a by-product from blast furnace slag, and at less expense if the process of blowing the steam through the liquid slag before it cools after being drawn from the furnaces proves to be successful. Slag wool has been produced for some time by melting slag with the addition of some limestone for flux. The relative merits of mineral wool made from siliceous limestones and slag wool have not been determined.

Eventually it is believed that it will be found that certain chemical composition or definite physical characteristics are important and these will be attained by mixing different ingredients just as is done in the manufacture of Portland cement. It is hoped that it will develop that some of the Pennsylvania limestones are suitable for this use.

LIME

Everyone is familiar with the use of limestone for the production of lime. In its manufacture all kinds of limestone have been used. Some of the stones burned are so impure as to scarcely deserve being classed with the limestones. Lime has been produced in several thousand places within the State and ruins of lime kilns are plentifully distributed in every limestone district.

The uses of lime are so numerous that it is inadvisable to even attempt a complete enumeration of them and not possible to discuss each use. The following pages therefore constitute a summary only. Some of the uses have already been discussed under agriculture, glass and pottery manufacture, paints, etc., in which lime and raw limestone are both used.

Mortar, plaster, and stucco. At one time practically all the lime made was used in the preparation of mortar and plaster and this use still accounts for about 28 per cent of the total annual production of the country. Ordinary mortar is a mixture of slaked lime, water, and sand. Cement, hair, plaster-of-Paris and other materials are frequently added. The mortar hardens by the evaporation of the water and the slow gradual change of the calcium hydroxide into calcium carbonate by combination with carbon dioxide from the air. Both magnesian and non-magnesian limes are used, each of which possesses certain advantages. High calcium lime when mixed with water will make more putty and will hold more sand, hence more mortar can be formed from it. On the other hand the shrinkage is greater and there is a greater tendency to crack. There is also a tendency for masons to overload the high calcium lime with sand. Mortar made with high magnesian lime is considerably stronger than high calcium mortar and can be spread more evenly, hence is generally preferred by masons. It is also whiter.

The sale of hydrate lime for mortar and plaster is steadily increasing as there is a tendency for lime to "burn" when insufficient water is added and the mixture is imperfectly stirred. Just what happens when the "burning" takes place is not well understood but the "burnt" lime is practically useless and when used in mortar is apt to break away, leaving small pits.

In most cases the exact color of mortar is a matter of indifference but plastering mixtures must conform to color specifications, usually the whiter the more acceptable. Lime is used in stucco and concrete to make these mixtures less permeable to water.

Sand-lime brick. Considerable lime is used in the manufacture of sand-lime brick, an industry that has shown remarkable development since 1901 when the first plant in this country began operations at Michigan City, Indiana. In 1920, seventeen States contributed to the total production of 169,761,000 bricks, valued at $2,490,283. Pennsylvania ranked sixth with a production of 10,840,000.

Sand-lime brick consists of about 85 per cent sand and 15 per cent hydrated lime. These two ingredients mixed with sufficient water to permit molding are pressed into shape and then cured by subjection to steam under pressure of 100 to 150 pounds for 7 to 12 hours. A chemical reaction takes place, producing amorphous monocalcium silicate ($CaOSiO_2$), which binds together the remaining sand particles. High calcium lime is better than magnesian lime in that it produces brick of greater strength. Complete hydration of the lime is essential and this is more readily accomplished with the high calcium variety. Alumina, if not more than 2½ per cent, is not objectionable and silica in the lime is likewise harmless if proper allowance is made for it.

The brick are white, unless artifically colored, and possess about the same hardness and porosity as ordinary clay building brick. They are more regular in shape and size than burned brick.

Silica brick. A similar product to sand-lime brick is silica brick used because of their refractory qualities in furnace linings. They are made by mixing some form of silica with hydrated lime. The mixture is then molded, dried and specially burned. Only high grade limestone is used, over 92 per cent $CaCO_3$ and not more than 3 per cent MgO.

Chemical uses of lime. The chemical uses of lime are so extensive that it is not possible to enter into a detailed description of even the most important. Perhaps no other substance is used in as varied manner in the chemical industry. Dr. M. E. Holmes* describes the various functions of lime as a chemical agent as follows:

"Lime is a dehydrating agent. It will combine with the occluded water and the water of constitution of certain chemical substances rendering them anhydrous. For this reason, lime finds use in the manufacture of alcohol, both ethyl and methyl, and in the petroleum refining industry for dehydrating crude petroleum and greases. It, therefore, commends itself to the attention of every manufacturer employing processes of dehydration.

"Lime is a coagulating agent. A suspension of lime contains charged particles which will neutralize the charge of colloidal material flocculating it and clarifying the liquid by 'settling out.' It is due to this specific property of lime that it finds extensive application in the sugar industry. It is used for defacating raw sugar juices, a process which is accelerated by carbonating and sulphitating the lime in suspension. The carbonated lime in settling carries with it flocculated and absorbed colloidal matter producing a clear clarified juice.

"The coagulating capacity of lime finds use for itself in the mining

*Holmes, M. E., Lime in the chemical and allied industries, Rock Products, vol. 24, No. 19, pp. 17-19, Sept. 1921.

industry. Ore slimes are made to coagulate and settle rapidly by flocculation with lime. The efficiency of the process is thereby greatly increased through reducing the time of operation. The use of lime in the artificial ice industry also depends upon the coagulating capacity of lime. Water suitable for artificial ice must be clarified and purified and the satisfactory process for this is the use of lime in combination with other reagents.

"Lime also finds use as a flocculating agent in the rubber industry. The latex may be flocculated with lime and the clays used in making the compounding ingredients are flocculated with lime to render them suitable as a filler for the rubber. The use of lime in the sorghum industry also depends upon its coagulating capacity. The sorghum juice is clarified with lime in preparing it for the boiling operation. The coagulating action of lime is also employed in the disposal of sewage whereby the sewage is clarified by coagulating the colloidal matter with lime in combination with other chemical substances. Similarly water supplies may be deodorized and deferridized. Waste waters are also coagulated and disposed of with the use of lime. The coagulating action of lime is one of its most important properties and its uses by virtue of this property are very numerous.

"Lime functions as an absorbent for gases. Being a basic substance it will readily absorb practically all acid gases. This property of lime makes it useful in the electrolytic-alkali industry in which it is used to absorb and combine with chlorine in making bleaching powder, alkali hypochlorites and chlorates. It is the absorbing capacity of lime which makes it useful in the fixation of atmospheric nitrogen, where it is used to absorb nitrogen oxides in making nitric acid. Lime also finds use in the paper industry. As a result of its capacity for absorbing gases, lime will absorb sulphur dioxide forming bisulphites and sulphites which are used for making paper pulp. For the same reason lime is used in purifying illuminating gas in which process it absorbs sulphur dioxide, hydrogen sulphide and hydrocyanic acid, rendering the gas non-corrosive to boilers and mental fixtures. The absorption of carbon dioxide by lime is a process employed in the carbonation of sugar juices and in the manufacture of magnesia insulating material and in the manufacture of phenol. In the wood distillation industry the absorption of acetic acid vapor by lime produces acetate of lime. Acetic acid may then be made from the acetate by distillation with sulphuric acid.

"Lime is a causticizing agent. As such it is used in reacting with alkali sulphates, carbonates and phosphates forming hydroxides. This property of lime makes it useful in the paper industry where it is used for making caustic soda for use in the soda and sulphate pulp process. Similarly it is used in making the bases for hypochlorites in the bleaching industry, and alkali salts in general in the inorganic chemical industry. The various hydroxides made by causticizing with lime can be combined with the many acids forming a long array of inorganic salts. The causticizing action of lime is employed in the soap industry. Soaps are alkali salts of organic acids made from hydroxides produced by causticizing with lime. The causticizing action of lime is employed in the textile industry also wherein cloth fibers are mercerized with alkalies produced by the caustic action of lime.

"Lime is a hydrolizing agent. As such it is employed in the manu-

facture of hydrolized glue which is used in the prevulcanization treatment of rubber. By hydrolysis of aluminum nitride the compound is decomposed forming ammonia. This is a part of a process that may develop into an important means of fixing atmospheric nitrogen. The hydrolytic action of lime is also used in treating cellulose for the manufacture of material suitable for making a pulp cloth.

"Lime is a saponifying agent. As such it is used in the treatment of fats, waxes and greases whereby organic compounds such as glycerine may be 'split off' and the alkaline-earth salts of the fatty acids produced. By this process the animal products industries produce glycerine, glues, soaps, lubricating greases and paints. Lime cleanses wool and unhairs hides. Lime is also used in saponifying oils and in making lubricating greases and tar products and for making roofing material and waterproofing compositions. Lime is used also to saponify organic salts and in making organic hydroxides in the dye and organic chemical industry.

"Lime is a solvent. As such it is used in the treatment of hides whereby the cementing material is disintegrated and removed. For this reason along with others it finds extensive use in the tanning industry. Lime will also dissolve casein and as such it is used largely in the cold water paint industry. Lime in fused slag will dissolve sulphur and phosphorus and thus it finds use in the metallurgical industry for purifying steel and other metals.

"Lime is an oxidizing agent. As such it is used in the electrothermic industry where it oxidizes carbon thereby reducing itself, forming calcium carbide. Similarly lime has been used in a simple laboratory way for making metallic calcium. Of much more importance, however, is the manufacture of calcium silicide whereby lime functions indirectly as an oxidizing agent.

"Lime is a reducing agent. As such it is used in the manufacture of calcium peroxide by reduction of hydrogen peroxide or other strong oxidizing agents. This is one of the newer uses of lime which may have important possibilities.

"Lime is a lubricating agent. As such it is used in the high temperature lubrication of dies in the drawing of steel wire. Its fineness and refractoriness make it especially suitable for this use.

"Lime is a fluxing agent. As such it is used extensively in the basic open hearth process for refining steel, and for the manufacture of pottery and porcelain in the ceramic industry.

"Lime is a catalyzing agent. It functions as such in the peroxidation of alkalies forming such products as sodium peroxide. It also catalyzes the formation of calcium cyanamide in the action of calcium carbide on nitrogen. Lime also catalyzes the vulcanization of rubber, and the hydrogenation of nitrogen in the Haber process of fixing atmospheric nitrogen. In the fusion of chromite with alkalies, lime functions as a catalyst in the preparation of alkali dichromates. The esterification of glycerine and the manufacture of chlorine in the Weldon chlorine process also involve the catalytic action of lime.

"Lime is an ionizing medium, whereby it finds application in the production of metals by electrolysis of fused metals and in the electrical method of sewage disposal.

"Lime is a refractory. Its melting point and sintering point are exceeded by only a very few substances. It finds use, therefore, as

such in the manufacture of dead burned dolomite, silica brick and the like as refractory lining for furnaces and as insulating material for steam pipes.

"Lime is a precipitating agent. As such it finds extensive use in the preparation of many inorganic and organic salts, in the winning of metals from ores and the preparation of rare earth oxides from monazite sand, in the preparation of absorption media such as iron hydroxide in the purification of water and in the preparation of colloidal pigments such as satin white.

"Lime functions in various capacities in distillation. Lime is used in the distillation of coal and oil shale to produce ammonia and ferrocyanides and to enrich and purify the coal gas. In the wood distillation industry lime is used in the distillation of pyroligneous acid in making aluminum acetate, acetic acid, actone and methyl alcohol. The distillation of gas works liquors with lime produces many thousand tons of ammonia yearly.

"It is futile to attempt to cover in one brief article all of the functions of lime as represented by its manifold uses. It would not be permissible, however, in any article on this subject to omit the use of lime as a base or neutralizing agent. As mentioned above, lime is the queen of bases and by virtue of its composition (CaO and $Ca(OH_2)$ belongs to that class of chemical substances called hydroxides which will neutralize acids. Lime is used for neutralizing resinous acids for use in making varnish and enamels in the paint industry, and for use in making stabilizing media for liquid fuels. Ores are neutralized with lime in ore flotation and in the cyanide process in the mining industry.

"Organic acids are neutralized with lime in making lubricants, oil cloth and candles. Tar acids are neutralized with lime in making roofing material, bituminous paint, sulphonate detergents and lubricants in the hydrocarbon industry. The citrate industry employs the use of lime for neutralizing and recovering citric acid. Arsenic acid is neutralized with lime in making calcium arsenate in the insecticide industry. The manufacture of many mineral products involves the use of an excess of acids which is neutralized with lime. In the dye industry excess acids must be neutralized in the manufacture of phenol, sulphonated napthalene and anthracene. In the explosive industry excess acid is neutralized with lime in the manufacture of nitroglycerine. In making saccharified cellulose such as sawdust cattle food, excess acid used in hydrating the woody material is neutralized with lime. In like manner the acids used in pickling steel are neutralized with lime and the residual acids in Keenes cement and dried leather may be rectified with the use of lime."

In the accompanying chart, prepared by the National Lime Association, the chemical uses of lime are classified under the following divisions.

A. Raw materials in the manufacturing industries

1. High temperature processes
2. Saponification
3. Dehydration
4. Hydrolysis
5. Causticization
6. Coagulation
7. Absorption of gases
8. High-pressure
9. Distillation
10. Precipitation
11. Neutralization
12. Solution
13. Miscellaneous

B. Sanitation
   1. Treatment of water supplies
   2. Treatment of sewage
   3. Miscellaneous sanitary uses
C. Purification of materials
D. Food for animals and plants
E. Catalytic processes
F. Utilization of by-products
G. General utility
H. Medicine
I. Miscellaneous

For most of the chemical uses the demand is for lime of a high degree of purity, but this is not true in some instances. In general limestone used for the manufacture of chemical lime should not contain more than 5 per cent of impurities. Similarly there is usually a preference for high calcium lime, yet there are some cases where a high magnesium lime is more valuable and still others where either type is equally acceptable. Emley* gives the following table in which "c" indicates high-calcium lime and "m" magnesian or dolomitic lime.

Chemical Uses of Lime

Agricultural industry:
- As a soil amendment, c. m.
- As an insecticide, c. m.
- As a fungicide, c. m.

Bleaching industry:
- Manufacture of bleaching powder, "Chloride of lime," c.
- Bleaching and renovating of rags, jute, ramie, and various paper stocks, c. m.

Caustic alkali industry:
- Manufacture of soda, potash, and ammonia, c.

Chemical industries:
- Manufacture of ammonia, c.
- Manufacture of calcium carbide, calcium cyanimid, and calcium nitrate, c.
- Manufacture of potassium dichromate and sodium dichromate, c.
- Manufacture of fertilizers, c. m.
- Manufacture of magnesia, m.
- Manufacture of acetate of lime, c.
- Manufacture of wood alcohol, c.
- Manufacture of bone ash, c. m.
- Manufacture of calcium carbides, c.
- Manufacture of calcium-light pencils, c.
- In refining mercury, c.
- In dehydrating alcohol, c.
- In distillation of wood, c.

Gas manufacture:
- Purification of coal gas and water gas, c. m.

Glass manufacture:
- Most varieties of glass and glazes, c.

Milling industry:
- Clarifying grain, c. m.

Miscellaneous manufactures:
- Rubber, c. m.
- Glue, c. m.
- Pottery and porcelain, c. m.
- Dyeing fabrics, c. m.
- Polishing material, c. m.

Oil, fat, and soap manufacture:
- Manufacture of soap, c.
- Manufacture of glycerine, c.
- Manufacture of candles, c.
- Renovating fats, greases, tallow butter, c. m.
- Removing the acidity of oils and petroleum, c. m.
- Lubricating greases, c. m.

Paint and varnish manufacture:
- Cold-water paint, c. m.
- Refining linseed oil, c. m.
- Manufacture of linoleum, c. m.
- Manufacture of varnish, c. m.

Paper industry:
- Soda method, c.
- Sulphite method, m.
- For strawboard, c. m.
- As a filler, c. m.

Preserving industry:
- Preserving eggs, c.

Sanitation:
- As a disinfectant and deodorizer, c.
- Purification of water for cities, c.
- Purification of sewage, c.

Smelting industry:
- Reduction of iron ores, c. m.

Sugar manufacture:
- Beet root, c.
- Molasses, c.

Tanning industry:
- Tanning cowhides, c.
- Tanning goat and kid hides, c. m.

Water softening and purifying, c.

*Emley, Warren E.: Manufacture and Use of Lime: U. S. Geol. Survey, Mineral Resources, 1913, Pt. II, pp. 1592-1593, Washington, 1914.

Lime sold in the United States in 1929 and 1930 by uses

Use	1929		1930	
	Short Tons	Value	Short Tons	Value
Building	1,640,827	$14,303,539	1,204,614	$10,050,270
Agricultural	338,329	2,387,901	343,111	2,372,779
Glass works	75,283	544,760	62,912	408,429
Paper mills	411,017	3,057,350	378,721	2,652.232
Sugar refineries	20,758	249,190	18,905	238,788
Tanneries	67,046	516,207	56,526	438,869
Metallurgy	578,488	3,258,992	415,692	2,371,222
Alcohol manufacture and dehydration	308	3,705	2,159	17,388
Alkali works (ammonia, soda, potash)	21,167	133,901	12,635	84,402
Bleaching powder	7,852	59,919	6,899	50,154
Bleach, liquid	18,047	155,384	13,775	112,685
Calcium acetate	21,284	155,783	3,105	20,040
Calcium carbide	30,999	183,388	26,332	162,311
Coke and gas manufacture (gas purification and plant by-products)	34,227	240,314	25,215	181,141
Glue	9,387	75,414	7,194	51,813
Insecticides (spraying materials)	26,890	228,713	25,618	211,639
Oil and fat manufacture	20,985	171,897	14,053	117.069
Paint (kalsomine, whitewash, varnish, etc.)	5,111	55,889	4,109	38,707
Rubber	4,789	40,501	4,200	34,926
Salt refining	2,184	16,201	3,752	26,568
Sand-lime and slag brick	42,540	312,427	29,506	208,164
Sanitation (sewage and garbage purification, etc)	4,437	30,428	2,898	17,846
Silica brick	18,391	139,856	14,929	105,986
Soap	30,575	171,753	32,860	176,894
Textiles	2,851	29,386	2,780	21,891
Water purification	156,117	1,206,603	161,805	1,201,073
Wood distillation	4,445	34,293	2,790	22,663
Undistributed*	40,991	367,303	39,423	348,036
Unspecified	145,811	1,085,909	119,622	827,422

*Lime used in acid neutralization and drying, acetic acid, asphalt and fertilizer filler, baking powder, bichromate refining, buffing compounds, calcium phosphate, cellulose, corn products, creameries and dairies, cyanide manufacture, disinfectants (chloride of lime, etc.) dyes, explosives, filtration, flotation, flour mills, food products, gelatin (edible), magnesia, medicine, nitrogen manufacture, oil refining, oxygen purification, retarder, and stock food.

Preparation of Lime. The method of burning lime has received much attention during the last few years. In some outlying districts in Pennsylvania the burning is still done in the open by piling up alternate layers of wood or bituminous coal and blocks of limestone so arranged as to cause a good draft. When the fuel is well ignited, earth is thrown over the top.

The home-made rock "pot" kiln has had wide use and in many sections there is one on almost every farm where the necessary lime for farm use was burned. These are now being abandoned, and the farmer buys his lime as needed.

Shaft kilns in which there is an outer casing of steel or stone and an inner lining of refractory material are now in general use. Rotary kilns similar to those used in Portland cement mills are also used but only when hydrated lime is produced because the stone for a rotary must be crushed so fine that no lump lime can be made.

Lime is marketed as ground quicklime, unslaked lump lime, and hydrated lime. For some purposes it is optional as to which is used but in certain manufactures the requirements demand one particular kind. Lump lime is ordinarily shipped in wooden or steel barrels, ground quicklime in air-tight iron casks, and hydrated lime in paper bags, sacks, or barrels.

Hydrated lime is made at the plant by passing the ground quicklime through patent hydrators, of which two kinds are widely used.

The exact amount of water necessary for complete hydration is added and the material constantly stirred during the process to thoroughly mix the water and lime. The product is decidedly superior to that obtained in the usual process where lump lime is slaked in a box by stirring with a hoe. Hydrated lime also undergoes carbonation or air-slaking more slowly and can be kept longer and shipped more freely.

A typical flow-sheet of the process of making pulverized limestones, quicklime, and hydrated lime, prepared by the National Lime Association, is reproduced below. Several lime plants in Pennsylvania are built in conformity with this scheme.

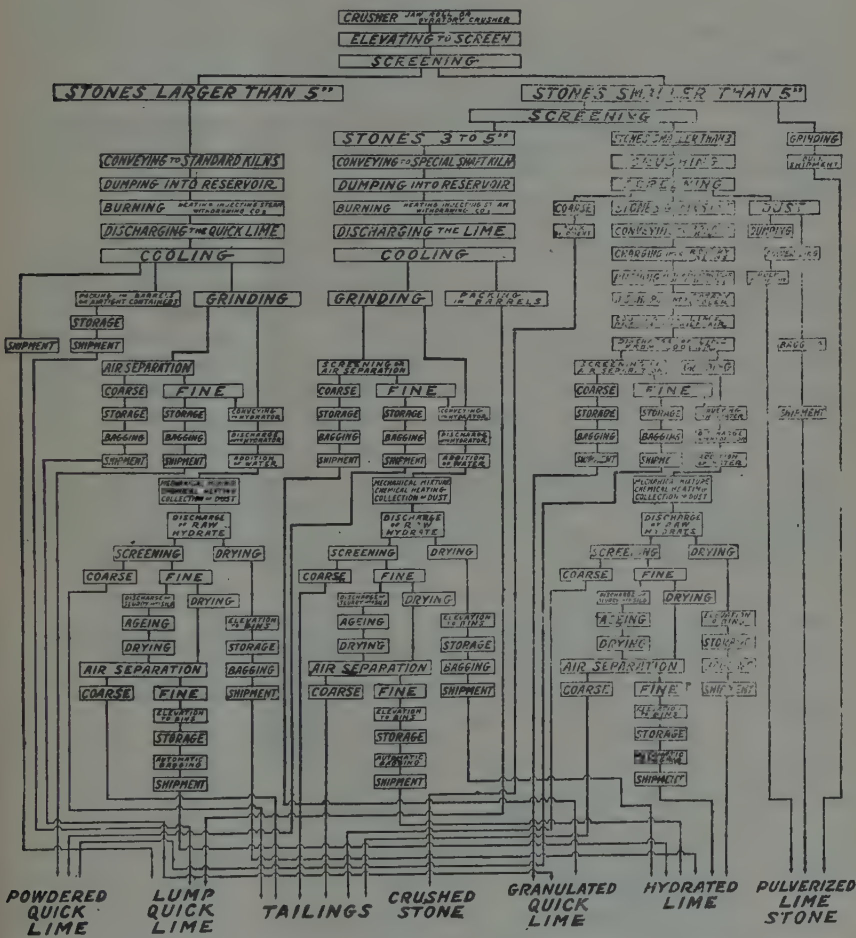


Fig. 3. Flow sheet showing process of making pulverized limestone and lime.

CHAPTER VII

GEOLOGIC AND GEOGRAPHIC DISTRIBUTION OF THE LIMESTONES OF PENNSYLVANIA

The limestones of the State were formed during a wide range of geologic periods from the pre-Cambrian to the Triassic and are distributed geographically so that there are only a very few counties in which limestones are lacking. In general, the thickest and most valuable limestones are found in the Lower Paleozoic formations which occur only in the southeastern, central and south central portions of the State, all lying to the southeast of the Allegheny Front. The uppermost Silurian and lower Devonian formations contain important limestones largely confined to the region of folded ridges and valleys of the central and southcentral portions. The Carboniferous formations contain useful limestones distributed through the west, central and southwestern part of the State. Approximately the northern third of the State is poorly supplied with limestones, especially the entire anthracite district, although within this belt there are scores of places where limestones have been quarried and utilized locally.

The accompanying map[1] of the State shows the distribution of the most important limestone belts of the region lying to the southeast of the Allegheny Front and containing rocks older than the Carboniferous. The distribution of the various groups of the Carboniferous are shown for the western part of the State where the limestones occur as individual layers, seldom more than ten feet in thickness, interbedded with a far greater amount of shale and sandstone. The individual limestones are of local occurrence but fairly abundant in the Allegheny, Monongahela, Washington and Greene formations.

In addition to the general State map, individual County maps showing the distribution of the principal limestones and most important limestone operations are included with the descriptions of the limestones of each County in Part II of the report.

GEOLOGIC TIME SCALE OF PENNSYLVANIA STRATA SHOWING OCCURRENCES OF LIMESTONES

Period-System	Epoch-Series	Group	Development of limestones	Uses
Quaternary	Pleistocene	Historic Glacial	No limestones	
Tertiary	A few local deposits, probably of this age, southeastern part of State		No limestones	
Cretaceous	Sparingly represented in the southeastern part of the State		No limestones	

Period-System	Epoch-Series	Group	Development of limestones	Uses
Jurassic	No deposits of this age in State			
Triassic	Newark	Brunswick Lockatong Stockton	Limestone conglomerate sparingly developed in Adams, Berks, Bucks, Cumberland and York counties	Ornamental building stone, lime
Permian	Dunkard	Greene Washington	Detailed classification of Carboniferous on later page. Numerous limestones interbedded with shales, sandstone and coal beds. Limestones numerous in western part of State, especially in southwestern counties	Agricultural lime, building lime, flux, cement, crushed stone for concrete and building
Pennsylvanian	Pittsburgh Pottsville	Monongahela Conemaugh Allegheny Pottsville		
Mississippian	Chester Meremec Waverly	Mauch Chunk Loyalhanna Pocono		
Devonian	Upper	Catskill	Thin, impure limestone locally developed in Bradford, Lycoming, Potter, Sullivan, Susquehanna, Tioga, Wayne counties	Agricultural lime
		Chemung	Thin, impure limestones locally developed in Bradford, Potter, Susquehanna and Tioga counties	Agricultural lime, flux
		Portage Genesee	No limestones	
	Middle	Hamilton	Thin, impure limestones locally developed in central part of State	Agricultural lime
		Marcellus Onondaga (Corniferous)	Limestones from 0 to 200 feet in thickness developed in Carbon, Monroe, Perry, Cumberland and Blair counties.	Lime and crushed stone

Period-System	Epoch-Series	Group	Development of limestones	Uses
Devonian	Lower	Oriskany Detailed description given on a later page.	Siliceous limestones developed in a few places in south central tarl part of State	Agricultural lime
		Helderberg	Valuable limestones outcropping in Bedford, Blair, Carbon, Centre, Clinton, Columbia, Franklin, Huntingdon, Juniata, Lebanon, Lycoming, Mifflin, Monroe, Montour, Northumberland, Perry, Schuylkill, Snyder and Union counties.	Lime (agricultural, building chemical), flux
Silurian	Upper Cayuga			
	Cayuga	Tonoloway	Outcrops with Helderberg limestone	Lime (agricultural building, chemical), flux.
		Salina Bloomsburg	Impure limestones locally developed in Montour County	Agricultural lime.
	Niagara	Lockport Clinton	Thin, impure limestones in central part of State	Agricultural lime.
	Medina	Tuscarora Juniata Oswego	No limestones	
Ordovician	Cincinnati Mohawk	Cambro-Ordovician limestones See detailed classification on later page	Limestones from 4,000 to 11,000 feet in thickness extensively developed in Adams, Bedford, Berks, Blair, Bucks, Centre, Chester, Clinton, Cumberland, Dauphin, Franklin, Fulton, Huntingdon, Juniata, Lancaster, Lebanon, Lehigh, Lycoming, Mifflin, Montgomery, Northampton, and York counties	Lime (agricultural, building, chemical) flux (dolomitic and non-dolomitic), cement, crushed stone for concrete and road metal, building stone, etc.
Canadian	Chazy Beekmantown Ozarkian			
Cambrian	St. Croixan Acadian Waucoban			
Keweenawan Animikian Huronian	Glenarm	Peach Bottom slate Cardiff conglomerate Peters Creek schist Wissahickon schist Cockeysville marble Setters quartzite	Locally developed in Chester County	Lime, flux, cement, and building material.

Period System	Epoch-Series	Group	Development of limestones	Uses
Laurentian		Franklin limestone	Locally developed in Berks, Bucks, Chester, and Northampton counties	Lime and building material.
		Hartley gneiss Baltimore gneiss		

*This time scale has been arranged to conform with the scale of the Pennsylvania Geological Survey, although B. L. Miller prefers the U. S. Geological Survey scale.

PRE-CAMBRIAN LIMESTONES

Pre-Cambrian limestones, more or less completely metamorphosed to marbles, occur in several localities in Chester, Bucks, Berks, and Northampton counties. There has been much discussion concerning their stratigraphic position but as the result of field conferences participated in by a number of geologists who are most familiar with the geology of the Piedmont Plateau the following classification has been adopted by the Pennsylvania Survey. The quoted descriptions have been furnished by F. Bascom.

Pre-Cambrian formations of southeastern Pennsylvania.

Glenarm series:
- Peach Bottom slate, Cardiff conglomerate (alternating layers schist, slate and conglomerate).
- Peters Creek schist ("chloritic sericitic quartz schists with chlorite muscovite schists").
- Wissahickon group ("thoroughly crystalline quartz-feldspar mica rock; gneiss and mica schist. A mica schist facies was formerly known as the Octoraro mica schist and regarded as Ordovician in age").
- Cockeysville marble ("coarsely crystalline, associated with gneiss and penetrated by pegmatites").
- Setters quartzite ("occasional and limited development of quartzite beds; in some places dominantly a mica gneiss").

Laurentian:
- Franklin limestone or marble ("coarsely crystalline, white with graphite and numerous silicate minerals").
- Baltimore gneiss ("sedimentary, medium to fine grained, banded gneiss with igneous intrusives. In some places thoroughly granitized").

The Franklin limestone, or the calcareous phase of the Franklin or Grenville formation, is developed in several very small areas in Chester, Bucks, Berks, and Northampton counties.

There are several small areas of Cockeysville marble in the southeastern part of Chester County, where several marble quarries were long operated. In recent years there has been little quarrying done and the large openings are filled with water. The limestone is developed in the vicinity of Doe Run, Avondale, and Landenberg.

CAMBRO-ORDOVICIAN LIMESTONES

Division into formations. The most extensive limestone series of the State belongs to the Cambrian, Canadian, and Ordovician systems. Until recently the evidence for separating the Cambrian, Canadian, and Ordovician rocks in Pennsylvania was lacking, because they are almost entirely composed of limestone and in most places in Pennsylvania fossils are few in these systems.

The geologists of the First Geological Survey of Pennsylvania put all these limestones into a single group called the No. II or Auroral series. The members of the Second Geological Survey designated the limestones as the No. II series although recognizing that it included the Calciferous, Chazy, and Trenton formations of New York where differentiations were more readily made. In 1892 the U. S. Geological Survey adopted the name "Shenandoah limestone" for the series, the name that is still used where sufficiently detailed work to permit differentiation has not been done. The geologists of the New Jersey Geological Survey have used the term "Kittatinny" to designate the same strata.

In recent years the series has been carefully studied in several places and divided into a number of different formations as shown by the accompanying diagram.

As shown in these sections the Cambro-Ordovician limestone series varies greatly in thickness in different parts of the State, the recent estimates ranging from less than 4,000 to more than 11,000 feet and some of the earlier as low as 2,000 feet. The characteristics also change from place to place so that the stratigraphic units or formations of one section may not be easily recognized in another section. However, these limestones are so familiar that a general description is more or less applicable to all of them.

Structural character. The Cambro-Ordovician limestones of Pennsylvania are all within the region of folded strata. They were folded at the close of the Ordovician period and again at the close of the Permo-Carboniferous period. In the Great Valley and other valleys lying to the southeast the folding was intense and in many places the beds were broken and displaced. In these sections complex folds and faults are so numerous that it is not possible to determine the actual structure except along streams where there are continuous exposures. It is difficult to trace any one bed from outcrop to outcrop and consequently no one has been able thus far to estimate the thickness of these limestones with any fair degree of certainty. The figures of thickness given in the table are admittedly mere approximations.

The Cambro-Ordovician limestones in the central part of the State have likewise been folded and faulted but to a considerably less degree. Even there strata are found with the individual beds vertical or overturned but the complexity gradually decreases westward to the Allegheny Front and the structural features can more readily be determined.

As would be expected the amount of jointing in the limestones varies.

In many places the joints are so numerous and so close together that it is impossible to obtain blocks for structural purposes. Almost everywhere in the State the Cambro-Ordovician limestones are closely jointed, yet on the other hand there are numerous localities where good building material is obtainable. The beds that have been most folded and faulted naturally contain more joints.

Lithologic character. The Cambro-Ordovician limestones of Pennsylvania exhibit practically all the variations in lithologic features that are found in limestones. We find thick massive beds and thin shaly beds; limestone conglomerates, limestone breccia, edgewise conglomerates, oolitic and occasionally pisolitic limestones; blue, gray, white, buff, and almost black limestones; limestones with so large a proportion of sand grains that it is optional whether they be called arenaceous limestones or calcareous sandstones, and limestones that grade into shales by the large admixture of mud; hard, compact limestones and porous cavernous ones, and in one place near Annville unconsolidated calcareous material that resembles finely pulverized limestone; ripple-marked, sun-cracked, and rain-pitted limestones and those in which there are no evidences of shallow water deposition; and limestones in which chert nodules and siliceous concretions are abundant.

Of special importance is the variation in the metamorphism or marmorization of the Cambro-Ordovician limestones of the State. Commonly a certain amount of crystallization is evident but in many places the stone has been transformed into excellent marble. In general the best marbles of these periods are found in the closely folded strata southeast of the Great Valley but locally in other places the metamorphism has been sufficient to convert the limestone into marble.

Paleontologic character. Throughout the State the Cambro-Ordovician limestones are characterized by the paucity of fossils. This is particularly true of the limestones of the Great Valley and regions lying to the southeast. Fossils are somewhat more plentiful in the central and south-central portions of the State but are markedly deficient in comparison with beds of similar age in New York and elsewhere. The Ordovician and Canadian members contain more fossils than the Cambrian and in certain restricted localities certain layers are well-filled with crinoid stems, brachiopods, bryozoa, trilobites, mollusca, etc. The general scarcity of fossils together with the complicated structure has made the stratigraphic study of these limestones very difficult.

Chemical composition. Any generalization concerning the chemical composition of the Cambro-Ordovician limestones might be misleading. The most common characteristic is their extreme variability in the amount of each of the ordinary constituents of limestones.

The greatest variation is in the amount of magnesium carbonate. This ranges from a fraction of 1 per cent to 48 per cent, exceeding the quantity present in the theoretical composition of dolomite. The lower strata (Cambrian) almost everywhere are highly magnesian and the upper (Canadian and Ordovician) beds less so, yet one finds occasional low magnesian limestones in the lower members and also

Columnar section of Cambrian and

<table>
<tr><th>Pa. Geol. Surv.
PERIOD</th><th>U. S. Geol. Surv.
PERIOD</th><th>First Geological Survey of Pennsylvania</th><th>Second Geological Survey of Pennsylvania</th><th>U. S. Geological Survey 1892 to 1908</th><th>Cumberland Valley (Stose, 1909)</th></tr>
<tr><td rowspan="2">ORDOVICIAN</td><td rowspan="4">ORDOVICIAN</td><td>III. Matinal shale and slate</td><td>III. Hudson River shale
III. Utica shale</td><td>Hudson River shale</td><td>Martinsburg shale (2000 feet)</td></tr>
<tr><td rowspan="7">II. Auroral limestone</td><td>II. c. Trenton limestone</td><td rowspan="7">Shenandoah limestone</td><td>Chambersburg limestone (100-750 feet)</td></tr>
<tr><td rowspan="3">CANADIAN</td><td>II. b. Chazy limestone</td><td>Stones River limestone (675-1050 feet)</td></tr>
<tr><td rowspan="5">II. a. Calciferous limestone</td><td>Beekmantown limestone (2300 feet)</td></tr>
<tr><td rowspan="7">CAMBRIAN</td><td>Conococheague limestone (1635 feet)</td></tr>
<tr><td rowspan="6">CAMBRIAN</td><td>Elbrook limestone (3000 feet)</td></tr>
<tr><td>Waynesboro sandstones and impure limestones (1000 ± feet)</td></tr>
<tr><td>Tomstown limestone (1000 ± feet)</td></tr>
<tr><td rowspan="3">I. Primal limestone</td><td rowspan="3">I. Potsdam (Chiques, Chikis Hellam or White Spot) sandstone</td><td rowspan="3">Chickies quartzite</td><td>Antietam sandstone (500-800 feet)</td></tr>
<tr><td>Harpers schist and Mont Alto quartzite member (2750 feet)</td></tr>
<tr><td>Weverton sandstone (1250 feet)</td></tr>
</table>

Ordovician rocks of Pennsylvania

Northampton, Lehigh, and Berks counties (Wherry and Miller, 1910 and later.)	Centre County (Moore, (1915 unpublished)	Blair and Huntingdon counties (Butts, 1918)	Southeastern Pennsylvania (Stose and Jonas 1922.)
Martinsburg shale (3000 feet)	Reedsville shale (825 feet)	Reedsville shale (1000 feet)	Cocalico, shale (1000 ± feet)
	Trenton limestone	Trenton limestone (320 feet)	
Jacksonburg cement limestone (250-600 feet)	Black River group: Rodman limestone	Rodman limestone (30 feet)	
	Black River group: Lowville limestone	Lowville limestone (180 feet)	
	Pamelia limestone, Carlim limestone (260 feet)	Carlim limestone (180 feet)	Conestoga limestone (500 ± feet)
Beekmantown limestone (1000 ± feet)	Bellefonte dolomite (1911 feet)	Bellefonte dolomite (1000 feet)	Beekmantown limestone (2000 ± feet)
	Axemann limestone (480 feet)	Axemann limestone (100 feet)	
	Nittany dolomite (1206 feet)	Nittany dolomite (1000 feet)	
	Stonehenge limestone (633 feet)		
Allentown limestone (1500 feet)		Larke dolomite (250 feet)	Conococheague limestone (900 ± feet)
	Mines dolomite (150 feet)	Mines dolomite (250 feet)	
	Gatesburg formation (800 feet)	Gatesburg formation (1750 feet)	
	Warrior limestone (688 feet)	Warrior limestone (250 feet)	Elbrook dolomite (500 ± feet)
		Pleasant Hill limestone (600 feet)	
		Waynesboro sandstone (250 ± feet)	
Tomstown limestone (1000 ± feet)			Ledger dolomite (1000 ± feet)
			Kinzers formation (150 feet)
			Vintage dolomite (500-650 feet)
Hardyston sandstone and quartzite (100-250 feet)			Antietam quartzite (150-200 ± feet)
			Harpers phyllite (1000-1500 + feet)
			Chickies quartzite (550-1000 feet.)
			Hellam conglomerate (150-600 feet)

high magnesian beds in the upper strata. Active search has been made in these limestones for dolomites for use in open hearth furnaces and for low-magnesian beds for cement and chemical uses. The efforts expended in both directions have been rewarded.

Certain members of the Cambro-Ordovician limestone series contain considerable aluminous material, so that rocks grade between limestone and shale. The shaly layers are always high in silica. In many places the siliceous and aluminous matter has been metamorphosed to sericite (called *damourite* by the geologists of the Second Geological Survey of Pennsylvania). In Northampton, Lehigh and Berks counties, the uppermost member of the Ordovician limestones, the Jacksonburg formation, is highly argillaceous and low in magnesian carbonate. It is the best stone in the State for the manufacture of Portland cement, for which purpose it has been extensively used. This formation is described in detail in a separate chapter on Portland cement.

The amount of silica varies likewise in the Cambro-Ordovician limestones. In places occasional beds composed almost entirely of silica constitute distinct sandstone layers. Nodules and even more or less continuous bands of black flint are present in many places. However, most of the silica present is in combination with alumina as aluminum silicates. In quarries worked for fluxing materials the presence of a highly siliceous bed, interstratified with those of low silica content, renders the whole deposit much less desirable.

Sulphur, phosphorus, manganese, and many other constituents are present in these limestones usually in negligible quantity.

Uses. The limestone industry of the State is largely based on the Cambro-Ordovician limestones. Low and even moderately high silica limestones, both high and low in their magnesian content, have been extensively quarried for fluxes. Nearly all the iron furnaces in the eastern half of the State have in the past obtained the major portion of their fluxing limestones from these strata but lately increasingly larger quantities have been brought in from other regions. In recent years careful search has been made in Pennsylvania for low-silica dolomites for open hearth use, and has been successful.

Most of the lime produced in the State is made from Cambro-Ordovician limestones and for this purpose both low and high magnesian materials have been employed.

These same limestones have furnished most of the crushed limestone for the highways of the State and considerable has been shipped to other States. In almost every case these limestones, except where very shaly, will meet the rigid specifications of the State Highway Department. Crushed stone for concrete, and ballast and pulverized stone for fertilizing and filler purposes have been obtained from these limestones.

Locally these strata can be utilized for the manufacture of Portland cement but in most places they contain too much magnesium carbonate. A narrow band of limestone low in argillaceous matter that extends continuously across Northampton County and part of Lehigh County and in a few places in Berks County has been extensively quarried for cement manufacture and some unusually pure

limestone in the Lebanon district has supplied the high grade stone required by some of the cement companies of the State.

The Cambro-Ordovician limestones have furnished much less structural material than one might expect from their accessibility. Comparatively few quarries have been opened primarily for building stone. The principal reason for this is the close spacing of joints and the irregularity in thickness of the beds. Years ago some highly desirable marble was quarried in the Chester Valley and it is probable that other regions where the metamorphism has been severe might yield marble of good grade.

In Chester and Montgomery counties there are several quarries in strata of this age where low-silica dolomites have been obtained for the extraction of magnesium carbonate.

DEVONIAN AND SILURIAN LIMESTONES

In the physiographic province known as the "Appalachian Valley" that extends across central Pennsylvania in a broad sweeping curve from New Jersey to Maryland, among the persistent rock strata are those grouped under the name of "Formation No. VI" or the "Lower Helderberg limestones" by the earlier Geological Surveys. Although not a unit, as can be seen by the correlation table that follows, the series is largely responsible for the numerous narrow steep-sided valleys that are such a prominent feature in the central part of the State. Underlain and overlain by argillaceous and siliceous strata, these calcareous beds are valley formers because of their soluble character in contrast to the less soluble shales and sandstones.

The Helderberg limestones occur where the strata have been thrown into great longitudinal folds which subsequently have been worn down by erosion. This brings the limestones to the surface as outcropping beds in numerous places. The map showing the surface distribution of the limestones exhibits their repetition and their weaving back and forth throughout the area. This feature is especially prominent in the south central part of the State.

The Helderberg limestones outcrop in the following counties: Monroe, Carbon, Schuylkill, Lebanon, Perry, Juniata, Mifflin, Snyder, Union, Northumberland, Montour, Columbia, Lycoming, Clinton, Centre, Huntingdon, Blair, Bedford, and Fulton.

The classification and correlation of the Helderberg limestones has long been a subject of dispute which even yet is not ended. One of the most recent studies on the subject based primarily on the paleontological characteristics, which undoubtedly are of the greatest value, is by John B. Reeside, Jr.* He collected specimens and carefully studied several sections in Central Pennsylvania. His conclusions are accepted by the writer and various portions of his report will be quoted in the following pages. Notwithstanding the acceptance, in the economic descriptions the Tonoloway is considered as a part of the Helderberg series. The following table is adopted from this report:

*Reeside, J. B. Jr., The Helderberg limestone of central Pennsylvania: U. S. Geol. Survey Prof. Paper 108, pp. 185-225, 1918.

Correlation of the Helderberg limestone and adjacent strata

	White, Montour County Grovania,*	White, Snyder County Selinsgrove,†	White, Northumberland County Dalmatia,†	Claypole, Perry County Clark's Mill‡	D'Invilliers, Mifflin County Lewistown‖	White,‖ Huntingdon County Mapleton¶	Platt, Blair County Tyrone§	White, Monroe County**	Reeside††
DEVONIAN	Oriskany sandstone Stormville shales Stormville conglomerate Stormville and Bastard limestone	Oriskany sandstone Stormville shales Stormville and Bastard limestones	Oriskany sandstone Stormville shales Stormville and Bastard limestones	Oriskany sandstone Flint shales Clarks Mill shales	Oriskany sandstone Lewistown limestone: Lime shale; Lower massive limestone	Oriskany sandstone Stormville shale Lewistown limestone: Lime shale; Massive limestone; Shaly limestone	Oriskany sandstone Lewistown limestone	Oriskany sandstone Stormville shales Stormville conglomerate Stormville limestone Decker Ferry limestone Decker Ferry sandstone Decker Ferry shale	Oriskany shales and sandstone Helderberg: New Scotland limestone; Coeymans limestone; Keyser limestone
SELURIAN	Bossardville limestone	Bossardville limestone	Bossardville limestone	Lewistown limestone				Bossardville limestone Poxono Island shales Poxono Island limestone	Tonoloway limestone

*Pennsylvania Second Geol. Survey Rept. G7, p. 88, 1883.
†Idem, p. 92, 93.
‡Idem, Rept. F2, p. 182, 1885.
‖Idem, Rept. F3, p. 256, 1891.
¶Idem, Rept. T3, 1886.
§Idem, Rept. T, 1881.
**Idem, Rept. G6.
††U. S. G. S. Prof. Paper No. 108, p. 186.

As the field investigations to secure data for this report did not permit sufficiently detailed study to establish the divisions of the series through the State, the lithologic descriptions of the various formations given by Reeside are quoted*

TONOLOWAY LIMESTONE

"The type exposures (pp. 187-188) of the Tonoloway limestone are in the lower slopes of Tonoloway Ridge, and the type locality is just west of Rock Ford, W. Va., where Great Cacapon River cuts through the ridge. Typically it is composed of finely laminated light-gray limestone and calcareous shale and is generally more shaly toward the top.

"The Tonoloway formation in central Pennsylvania has, at all the exposures studied except Tyrone, the same characteristic lithology, consisting of platy, in places laminated fine-grained gray limestones and calcareous shales. The uppermost beds in the Susquehanna region are heavy, pure, and very dark. At Tyrone the strata referred to the Tonoloway are relatively light cream-colored to buff limestones, in places platy and in places containing shale. These beds probably represent a special facies very much like the Wills Creek shale of Maryland. Indeed, if there were sufficient evidence of an unconformity and hiatus at the top, the lithology of these beds would suggest their correlation with the Wills Creek. The Tonoloway at Tyrone also contains a bed of material that seems to be siliceous oölite.

"The Tonoloway is not fully exposed at any of the localities studied. The maximum thickness observed is 325 feet.

"The Tonoloway and Keyser succession has been considered by most observers as uninterrupted, but Ulrich believes the two limestones to be separated by a marked break. The change from the platy fissile gray limestone of the Tonoloway to the much thicker-bedded nodular bluish limestone of the Keyser, in some places very dark in color, is usually sharp. Even where the uppermost Tonoloway is massive, the nodular structure of the Keyser permits a separation."

HELDERBERG LIMESTONE

General character. "The Helderberg formation (p. 188) is a series of calcareous deposits of varied character. It includes some shale but is chiefly limestone. In lithology individual beds may represent any stage in the gradation between a coarse agglomeration of fossil fragments and a dense, very fine-grained subcrystalline rock, or between a somewhat calcareous shale and a laminated impure limestone. Some parts of the formation have in all exposures much bedded chert, and locally chert is present as nodules in other parts of the formation. In very minor quantity arenaceous limestone and even calcareous sandstone are present.

"Four members are recognized in the Helderberg limestone—the Keyser limestone at the base, and above it, in order, the Coeymans limestone, the New Scotland limestone, and the Becraft limestone."

Keyser limestone member. "The Keyser limestone forms the larger part of the Helderberg of central Pennsylvania. It

*Reeside, J. B. Jr., The Helderberg limestone of central Pennsylvania: U. S. Geol. Survey Prof. Paper 108, pp. 185-225, 1918.

is divisible into two major lithologic units—a lower limestone series with many nodular layers and an upper series of relatively shaly limestone, which contains very few nodular beds. At Tyrone no nodular limestone whatever was recognized, but everywhere else it is a prominent feature. At Mapleton and near Lewistown a thick bed of very pure massive crinoidal limestone lies near the base of the member. Here and there the Keyser contains chert and in many places Stromatopora-bearing beds.

"The thickness is variable in the area studied, ranging from 88 feet in one of the Tyrone sections to 202 feet at Selinsgrove Junction."

Coeymans limestone member. "The Coeymans member is variable in its lithology. In the west it is locally arenaceous at the base and consists of coarse crinoidal limestone in the upper part. Farther east this sandy character extends through the whole of the member and becomes so pronounced at Grovania that the Coeymans is a sandstone. Usually chert is present.

"The thickness of the Coeymans in the sections studied varies from 3 to 10 feet, though it is possible that the minimum thickness should be increased by including some of the overlying limestone."

"The Coeymans-Keyser boundary is everywhere strikingly clean cut. The uppermost beds of the Keyser are platy, banded impure limestones. The base of the Coeymans is coarse, commonly arenaceous limestone or sandstone. The faunal change is likewise sharp."

New Scotland limestone member. "The New Scotland member usually has a thin bed of limestone at its base, above which lie shales, interbedded in many places with impure limestone and with white chert.

"In the vicinity of Dalmatia the basal limestone is very thin or lacking. It was likewise not observed in Perry County. At Tyrone it is 12 feet thick; at Lewistown, 6 feet; at Selinsgrove Junction, 12 feet; at Grovania it seems to be about 13 feet thick and contains much shale. The limestone is arenaceous at Selinsgrove Junction, but in most other places it is simply a coarse-grained bluish-gray fossiliferous rock."

"The shale is ashy gray, fissile or splintery, and fine grained and contains more or less impure limestone in thin layers. It weathers yellow and is not usually very fossiliferous. The only measurement of the thickness, made at Selinsgrove Junction, gives a total of 44 feet. Some uncertainty as to the position of the upper boundary renders the accuracy of this figure only approximate."

"The New Scotland-Coeymans boundary is not well defined lithologically."

Becraft limestone member. "No lithologic or faunal evidence of the presence of the Becraft member of the Helderberg was obtained at any locality studied."

Uses. The Helderberg (including Tonoloway) limestones have been quarried in hundreds of places throughout the counties where they outcrop. The main use has been for the manufacture of agricultural lime, building lime, for flux, and for road metal and concrete. In a few places high grade chemical lime has been made.

Many of the descriptions by counties that follow are by Dr. Lloyd

W. Fisher who did the major portion of the field work in the Helderberg areas.

ONONDAGA LIMESTONE

This member has been described fully by Kindle*, from whose report the following notes have been compiled. "Near the mouth of Flat Brook Creek (New Jersey) the Onondaga limestone crosses to the Pennsylvania side (Monroe County) of Delaware River." Until Kindle's studies were made, the member was not recognized west of Stroudsburg, but is now known from several localities across the State and into Maryland, although it is not always the typical, cherty limestone of Monroe County and the Hudson Valley. In the western localities where the Onondaga has been recognized it is chiefly shale.

CHEMUNG LIMESTONE

Not only the Upper Devonian, but also the upper part of the Middle Devonian members carry occasional, thin limestones worked locally and consisting chiefly of masses of broken shells. They are of almost no consequence. Therefore, further mention of them is confined to discussions of the limestones by counties. These Upper Devonian deposits are chiefly confined to the eastern half of the northern tier counties.

CARBONIFEROUS LIMESTONES

Geographic and stratigraphic position. The Carboniferous rocks appear at the surface over more than one-half of the State. They are the only, or practically the only, outcropping rocks in Allegheny, Armstrong, Butler, Cambria, Clarion, Clearfield, Fayette, Greene, Indiana, Jefferson, Lawrence, Mercer, Venango, Washington and Westmoreland counties and are well developed in the following additional 30 counties: Blair, Bradford, Cameron, Carbon, Centre, Clinton, Columbia, Crawford, Dauphin, Elk, Erie, Forest, Fulton, Huntingdon, Luzerne, Lycoming, McKean, Monroe, Northumberland, Perry, Pike, Potter, Schuylkill, Somerset, Sullivan, Susquehanna, Tioga, Warren, Wayne, and Wyoming.

The Carboniferous System is subdivided into periods and formations as follows:

- Permian
  - Dunkard series (Upper Barren Measures)
    - Greene group
    - Washington group
- Pennsylvanian
  - Pittsburgh series
    - Monongahela group (Upper Productive Measures)
    - Conemaugh group (Lower Barren Measures)
    - Allegheny group (Lower Productive Measures)
  - Pottsville series (Conglomerate)
- Mississippian
  - Chester series—Mauch Chunk
  - Meremec series
    - Loyalhanna limestone
  - Waverly series
    - Pocono subseries

With the exception of the anthracite regions, where all of the

*Kindle, E. M., The Onondaga fauna of the Alleghany region: U. S. Geol. Survey, Bull. 508, pp. 23-34, 1912.

strata above the Pottsville conglomerate are grouped under the name "Coal Measures," the above classification is followed throughout the State, although the thinning and changing character of the Pocono, Mauch Chunk, and Pottsville, proceeding westward from the anthracite regions, renders exact correlations somewhat uncertain in some places.

In addition, each of the formations has been subdivided into members that have been given more or less local names. The common practice is to name certain beds that either are of economic importance or are fairly persistent and uniform so that they serve as good horizon markers. Thus almost every coal or limestone bed has received a specific name. Many of the limestones that are of little or no commercial value are useful in correlation as they are apt to be more persistent than the coals, sandstones, or shales and various coals are identified by their position with reference to particular limestones. In the county descriptions that follow, many limestones are mentioned even though they are insignificant.

Limestones have been quarried from each of the formations or groups listed although they may be thin, non-persistent, and of inferior quality. The best and most abundant limestones are developed in the Allegheny, Monongahela, and Washington groups. The Vanport limestone of the Allegheny is the most valuable limestone of the Carboniferous strata of the State.

Character and use. The Carboniferous limestones of Pennsylvania represent both marine and fresh-water deposition. In some cases it is somewhat uncertain whether they are marine or fresh water deposits. The marine limestones contain many fossils, as a general rule, whereas the fresh-water beds are deficient in organic remains although careful search may reveal the presence of occasional minute shells.

The fresh-water limestones resemble each other much more than the marine ones. They are almost invariably bluish-gray to a dove-colored gray or slightly yellow and weather to a chalky white. They are compact and have a tendency to break with a prominent conchoidal fracture. They are so soft that they rarely fulfill the rigid specifications for road metal, and in addition are, in the main, highly argillaceous. They are generally low in magnesium carbonate. They are also extremely variable, frequently undergoing extreme changes in thickness, physical characteristics, and chemical composition within a few miles.

In contrast, the marine limestones of the Carboniferous present more variations in their physical and chemical composition but individual beds maintain their diagnostic features over much wider areas. The Vanport, Ames, and Greenbrier, all of marine origin, can be recognized by their physical characteristics alone over wide areas.

The Carboniferous limestones of the State have been most widely used for agricultural lime, most of which has been made in small kilns for local use. Much lime has also been made by heap roasting. Formerly fluxing limestone was obtained in many places but at present only stone of good quality is desired for blast furnace use and the Vanport limestone of the Allegheny group is the only satisfactory one. The same limestone is the only one that is being utilized for the manufacture of Portland cement although it is possible that some others might be of some value for this purpose. A similar statement might be made concerning the uses of the Carboniferous limestones for road

metal, chemical lime, and for construction purposes. Locally, however, poor grade stone has been used in preference to stone of better quality that would have to be shipped in.

Unlike the older limestones of the State, the Carboniferous limestones are almost exclusively confined to regions where the folding action has been slight. They therefore are flat-lying or have gentle dips. Most of them outcrop along the sides of the steep-sided valleys that so largely prevail in the western part of the State. This facilitates the opening of small hillside quarries at the outcrop but presents great difficulty in the development of large quarrying operations unless the stratum sought caps the hill or lies so near the top that the overburden of shale and sandstone is thin. Where the limestone is sufficiently valuable to justify underground mining it is an easy matter to follow in the hill from the outcrop. The valuable Vanport limestone is being mined in several places and in at least one locality the upper Freeport has also been mined.

The Carboniferous limestones of the State are most numerous in the southwestern portion and become less abundant and, in general, of less economic importance northward and northeastward. For example, the Carboniferous limestones of the two northern tiers of counties as well as those of the entire anthracite region are negligible while about a dozen of the counties in the southwestern portion of the State contain fairly abundant limestone.

SUMMARY OF PRINCIPAL CARBONIFEROUS LIMESTONES OF PENNSYLVANIA

Permian System.

Greene group:
- Windy Gap limestone.
  - Greene Co. 8 to 10 feet. Lime.
- Nineveh limestone.
  - Greene Co. 5 to 10 feet. Lime.
  - Washington Co. Lenses containing some massive beds. Road metal.
- Claysville limestone.
  - Washington Co. 6 to 8 feet. Lime, road metal.
- Prosperity limestone.
  - Washington Co. 10 to 12 feet. Lime.
- Donley limestone.
  - Washington Co. 6 feet. Road metal.

Washington group:
- Upper Washington limestone.
  - Fayette Co. Thin, unimportant.
  - Greene Co. 4 to 15 feet. Road metal, lime.
  - Washington Co. 4 to 36 feet. Road metal, lime.
- Jollytown limestone.
  - Greene Co. 5 feet. Of little value.
  - Washington Co. Thin, unimportant.
- Middle Washington limestone.
  - Greene Co.
  - Washington Co. 10 to 30 feet. Road metal, lime.
- Blacksville limestone.
  - Greene Co. 3 feet, not important.
  - Washington Co. 3 to 5 feet, unimportant.
- Lower Washington limestone.
  - Fayette Co. Thin, unimportant.
  - Greene Co. 4 feet, of little value.
  - Washington Co. 30 feet. Road metal, lime.
- Colvin Run limestone.
  - Allegheny Co. Locally developed, thin, unimportant.
  - Greene Co. 3 feet, of little value.
  - Washington Co. Thin, unimportant.
  - Westmoreland Co. Thin, unimportant.
- Mount Morris limestone.
  - Allegheny Co. Thin, unimportant.
  - Greene Co. 1 to 2 feet, non-persistent, of little value.
  - Washington Co. Thin, unimportant.
  - Westmoreland Co. Thin, unimportant.

Pennsylvanian System.

Monongahela group:

Waynesburg limestone.
Allegheny Co. 1½ feet, unimportant.
Fayette Co. 8 to 35 feet. Lime.
Greene Co. 10 feet. Lime.
Washington Co. 4 to 20 feet. Locally important.
Westmoreland Co. 8 to 35 feet. Lime.
Uniontown limestone.
Allegheny Co. Variable. Lime.
Fayette Co. 10 feet. Flux, lime, road metal.
Butler Co. 0-22 feet. Flux, lime, road metal.
Washington Co. 30 to 50 feet. Lime, flux, road metal.
Westmoreland Co. 10 feet. Flux, lime, road metal.
Benwood (Great) limestone.
Bulger (Upper Benwood) limestone.
Dinsmore (Lower Benwood) limestone.
Allegheny Co. 150 feet, valuable. Lime, road metal.
Armstrong Co. 25 feet. Lime.
Fayette Co. 85 feet. Lime, road metal.
Greene Co. 150 feet thick (maximum), variable composition. Lime.
Indiana Co. 25 feet. Lime.
Washington Co. Variable. Lime.
Westmoreland Co. 85 feet. Lime, road metal.
Fishpot (Sewickley) limestone.
Allegheny Co. Thin, impure, unimportant.
Fayette Co. 0 to 35 feet. Lime, flux.
Somerset Co. Limited distribution, unimportant.
Washington Co. Discontinuous, thin, unimportant.
Westmoreland Co. 0 to 35 feet. Lime, flux.
Redstone limestone.
Allegheny Co. Thin, impure, unimportant.
Fayette Co. 10 to 20 feet. Lime, flux.
Somerset Co. Thin, unimportant.
Washington Co. Thin lenses of limestones and shales, impure. Lime.
Westmoreland Co. 10 to 20 feet. Lime, flux.

Conemaugh group:

Undifferentiated limestones (Jefferson Co.)
Upper Pittsburgh limestone.
Allegheny Co. Variable. Lime.
Beaver Co. Variable. Lime.
Pittsburgh limestone.
Armstrong Co. 5 feet. Lime.
Cambria Co. Thin, unimportant.
Indiana Co. Thin, unimportant.
Westmoreland Co. Thin, unimportant.
Lower Pittsburgh limestone.
Allegheny Co. Variable. Some good for lime.
Beaver Co. Variable. Some good for lime.
Somerset Co. Thin, unimportant.
Washington Co. Thin, of little value.
Little Clarksburg limestone.
Washington Co. Thin, of little value.
Clarksburg limestone.
Allegheny Co. Thin, unimportant.
Beaver Co. Thin, unimportant.
Somerset Co. Discontinuous. Lime.
Westmoreland Co. Thin, unimportant.
Barton limestone.
Allegheny Co. Thin, unimportant.
Beaver Co. Thin, unimportant.
Cambria Co. Thin, unimportant.
Indiana Co. Thin. Lime.
Somerset Co. 3 to 11 feet. Promising.
Westmoreland Co. Thin, unimportant.
Berlin limestone.
Somerset Co. Lack of information.
Coleman limestone.
Somerset Co. Lack of information.
Philson limestone.
Somerset Co. Thin, unimportant.
Ames limestone.
Allegheny Co. 6 to 30 inches. Impure. Lime.
Armstrong Co. 2 to 3 feet. Impure, unimportant.
Beaver Co. 6 to 30 inches. Impure. Lime.
Butler Co. Thin, unimportant.
Cambria Co. 4 feet. Impure.
Fayette Co. 4 feet. Unimportant.
Indiana Co. 4 feet. Impure.
Washington Co. 2 to 8 feet. Unimportant.
Westmoreland Co. 4 feet. Unimportant.
Pine Creek (Upper Cambridge) limestone.
Allegheny Co. Thin, unimportant.
Beaver Co. Thin, unimportant.
Butler Co. Thin, unimportant.
Westmoreland Co. Thin, unimportant.

Conemaugh group—Continued.

Brush Creek (Lower Cambridge) limestone.
Allegheny Co. Thin, unimportant.
Armstrong Co. Thin, unimportant.
Beaver Co. Thin, unimportant.
Butler Co. Thin, unimportant.
Westmoreland Co. Thin, unimportant.

Allegheny group:

Upper Freeport limestone.
Armstrong Co. Variable thickness, 5 to 18 feet. Lime.
Beaver Co. 2 to 7 feet. Lime.
Butler Co. 2 to 5 feet. Impure.
Cambria Co. 0 to 10 feet. Lime.
Center Co. Thin, of little value.
Clarion Co. Variable thickness. Lime.
Clearfield Co. 3 to 15 feet. Lime.
Elk Co. 2 feet. Lime.
Fayette Co. 3 to 18 feet. Lime.
Indiana Co. 0 to 10 feet. Lime.
Jefferson Co. 3 to 15 feet. Lime.
Lawrence Co. 2 feet. Unimportant.
Somerset Co. Variable thickness. Unimportant.
Westmoreland Co. 3 to 18 feet. Lime.
Lower Freeport (Butler) limestone.
Armstrong Co. Thin, of little value.
Beaver Co. 3 to 9 feet. Lime.
Butler Co. 3 feet. Unimportant.
Cambria Co. 4 feet. Lime.
Centre Co. 3 feet. Unimportant.
Clarion Co. Thin, unimportant.
Clearfield Co. 2 to 8 feet. Lime.
Elk Co. 4 feet. Lime.
Fayette Co. 2 to 4 feet. Unimportant.
Indiana Co. 4 feet. Lime.
Jefferson Co. 2 feet. Lime.
Somerset Co. Thin, unimportant.
Westmoreland Co. 2 to 4 feet. Unimportant.
Johnstown limestone.
Cambria Co. 6 feet. Lime, cement.
Centre Co. Thin, unimportant.
Clearfield Co. 2½ feet. Lime.
Elk Co. 2 to 6 feet. Of little value.
Fayette Co. 8 feet. Not continuous. Lime.
Indiana Co. 5 feet. Lime.
Jefferson Co. 2½ feet. Lime.
Somerset Co. 2 to 8 feet. Lime.
Westmoreland Co. 8 feet. Lime.
Vanport (Ferriferous) (Clermont) limestone.
Armstrong Co. 20 feet. Lime, flux, road metal.
Beaver Co. 5 to 19 feet. Flux, lime, road metal. Important.
Butler Co. 0-22 feet. Flux, lime, road metal. Very important.
Centre Co. Thin, unimportant.
Clarion Co. 10 to 20 feet. Lime, flux, road metal.
Elk Co. 6 to 10 feet. Lime.
Indiana Co. 4+ feet. Lime.
Jefferson Co. 0 to 6 feet. Lime.
Lawrence Co. 0-23 feet. Flux, lime, road metal. Very important.
McKean Co. 6 to 8 feet. Lime.
Mercer Co. 8+ feet. Fairly important.
Venango Co. 0-20 feet. Flux, lime, road metal. Important.
Benezette limestone.
Elk Co. 1 foot. Of no value.

Pottsville series.

Upper Mercer (Mahoning, Upper Wurtemburg) limestone.
Butler Co. Thin, unimportant.
Lawrence Co. 2 to 4 feet.
Mercer Co. 2 feet. Flux.
Mercer (Lower Mercer) (Lower Wurtemburg) limestone.
Armstrong Co. 6 to 10 feet. Impure. Of little value.
Beaver Co. 8 to 12 inches. Unimportant.
Butler Co. Thin, unimportant.
Lawrence Co. 2½ feet. Lime.
Mercer Co. 2 to 4 feet. Lime, flux.

Mauch Chunk series.

Greenbrier limestone.
Fayette Co. 3 to 40 feet. Road metal, lime.
Fulton Co. Shales and limestone. Lime.
Somerset Co. Important. Lime.
Westmoreland Co. 3 to 40 feet. Road metal, lime.

Meremec series

Loyalhanna limestone.
Blair Co. 40 feet. Road metal.

Meremec series—Continued.

Cambria Co. 45 feet. Paving blocks.
Fayette Co. 60 feet. Ballast, paving blocks.
Indiana Co. 45 feet. Paving blocks.
Somerset Co. 0-20 feet. Lime, road metal.
Westmoreland Co. 60 feet. Ballast, paving blocks.

Pocono series.

Upper Meadville limestone.
Crawford Co. 1 foot. Of little value.
Lower Meadville (Marion Creek) limestone.
Crawford Co. 2 feet. Lime.
McKean Co. 5 feet. Impure, unimportant.
Cassewago limestone.
Crawford Co. 1 to 2 feet. Lime.
Erie Co. 1 to 2 feet. Lime.
Undifferentiated limestones.
Clinton Co. Thin. Of little value.
Luzerne Co. 12 to 15 inches. Lime.
Potter Co. Thin. Of little value.
Sullivan Co. 12 feet. Impure. Lime.

TRIASSIC LIMESTONES

The Triassic strata of Pennsylvania in the form of a curved band about 10 to 40 miles wide extending across the State from New Jersey to Maryland in Northampton, Lehigh, Bucks, Berks, Lebanon, Dauphin, Lancaster, York and Adams counties consist mainly of shales and sandstones. Some thin impure fine-grained interbedded limestones are developed locally but are of no particular value. Of considerable value are some unique limestone conglomerates or limestone breccias that have been noted in a number of localities, especially at or near the northwestern boundary and near the base of the Brunswick formation. This type of rock is variable in character and distribution and grades into a quartz conglomerate or into a sandstone. In certain places it has been possible to map a Brunswick conglomerate and even to differentiate cartographically the siliceous and the calcareous phases. Elsewhere the conglomerate is local, occurring as thin lenses and containing pebbles of shale, sandstone, and limestone in a mud cement. Near the surface the limestone fragments may have been removed by solution leaving open cavities. Some of the conglomerate lenses are several hundred feet thick.

Potomac marble. The conglomerates in which all or nearly all the pebbles are limestones are very striking and from their occurrence along the Potomac River a short distance east of Harpers Ferry have received the name Potomac marble. Along the Potomac River the limestone pebbles are set in a matrix of red sandy shale.

In Pennsylvania the Potomac marble has been observed in a number of places but in few places does it have the brilliant color contrasts exhibited at the type locality. More commonly both the fragments and the matrix are dull gray or greenish gray. Some typical exposures of the rocks can be seen near Springtown, Bucks County; near Center Valley, Lehigh County; along Schuylkill River a few miles below Reading, Berks County; northeast of Bainbridge, Lancaster County; along Yellow Breeches Creek, 2 miles north of Lisburn, along Susquehanna River near Marsh Run, near Dillsburg, York County, and near Orrtanna and Fairfield, Adams County.

On the whole the Potomac marble does not possess much value as it is apt to be too impure to be used for flux or lime, and the fragments too feebly cemented for use as a building stone. In places, however, ornamental stone for interior use might be obtained. The only places in the State, as far as known, where this stone has been utilized are

near Dillsburg, York County, near Klapperthall, Berks County, and in the southwestern part of Adams County. In these places it has been used for agricultural lime.

Since this Triassic conglomerate, Potomac marble, has never been quarried in Pennsylvania as a building or ornamental stone but has been rather extensively quarried in Maryland, the following pages descriptive of it are abstracted from a report on "The Character and Distribution of Maryland Building Stones," by E. B. Mathews.[1]

"The most interesting building material in the entire State of Maryland is the 'Potomac marble,' 'calico rock' or 'Potomac breccia,' which has been used occasionally for the greater portion of the century. The chief interest in this rock arises from the fact that it is the only true conglomerate or breccia marble that has ever been utilized to any extent in the United States.[2]

"This conglomerate is found in several places along the eastern slope of the Blue Ridge and is most extensively quarried in the vicinity of Point of Rocks, Frederick county near Washington Junction on the Baltimore and Ohio Railroad. The quarries are small affairs, which have been operated spasmodically. The one in operation at the present time is located about a mile east of the Washington Junction station on a spur which runs northeasterly from the Metropolitan Branch.

"This rock was first brought into notice by Mr. B. H. Latrobe, Superintending Architect in the construction and repair of the Capitol and White House before and after the war of 1812. In his report on the public buildings, read February 14, 1817,[3] Mr. Latrobe gives the first account of the use of this marble as a building stone, as follows: 'For the columns, and for various other parts of the House of Representatives, no free-stone that could be at all admitted has been discovered. Other resources, therefore, were sought after. A stone hitherto considered only as an encumbrance to agriculture, which exists in inexhaustible quantity at the foot of the most southeasterly range of our Atlantic mountains—probably along the greatest part of their extent, but certainly from the Roanoke to the Schuylkill, and which the present surveyor of the capitol, and probably others, had many years ago discovered to be a very hard, but beautiful marble—this stone was examined, and, after much labor and perseverance, has been proved to answer every expectation that was formed, not only of its beauty, but of its capacity to furnish columns of any length, and to be applicable to every purpose to which colored marble can be applied.

'The present commissioner of public buildings has, therefore, entered into a contract for all the columns, and progress has been made in quarrying them. They may be procured each in a single block should the transportation be found convenient.

'A block of one of the pilasters lies ready to be brought down to Washington, and will, probably, arrive in a few days. The quarries are situated in Loudoun County, Virginia, and Montgomery County, Maryland.'

"The columns which were then procured are still standing in the

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[1] Mathews, E. B., Maryland Geol. Survey, vol. 2, pp. 187-193, 1898.

[2] Merrill, G. P. Stones for building and decoration, New York, John Wiley and Sons, 1891, p. 92.

[3] Senate Documents, 14th Congress, 2nd Session, No. 101, pp. 3 and 6.

old House of Representatives, now used for the sittings of the Supreme Court. The quarries whence they were obtained have never been fully developed, although Mr. Latrobe thought that he had found in the newly discovered marble of the Potomac an inexhaustible resource of the most beautiful building materials situated easily accessible by water. There is some doubt as to the exact location of the particular source of these blocks used in the capitol, although they were monoliths of considerable size for the time and the primitive means of transportation.

"A few years later in his paper on the geology of the Southern States the Rev. Elias Cornelius* gives the following account of this brecciated limestone:

'It is also in the valley of this river (Potomac), and not far from its famous passage through the Blue Ridge, that immense quarries of beautiful breccia have been opened. This rock was first brought into use by Mr. Latrobe, for some years employed by the government as principal architect. It is composed of pebbles, and fragments of siliceous and calcareous stones of almost every size, from a grain, to several inches in diameter, strongly and perfectly cemented. Some are angular, others rounded. Their colors are very various, and often bright. Red, white, brown, gray and green, are alternately conspicuous with every intermediate shade. Owing to the siliceous stones which are frequently imbedded through the mass, it is wrought with much difficulty; but when finished, shows a fine polish and is unquestionably one of the most beautifully variegated marbles, that ever ornamented any place. It would be difficult to conceive of anything more grand than the Hall of the Representatives, in the Capitol, supported at it is by twenty or thirty pillars formed of the solid rock, and placed in an amphitheatrical range; each pillar about three feet in diameter, and twenty in height. Some idea of the labor which is employed in working the marble may be formed from the fact, that the expense of each pillar is estimated at five thousand dollars. The specimens in your possession, are good examples of its general structure, but convey no adequate idea of its beauty.'

"The words of commendation and the beauty of the columns of the Capitol led the regents of the Smithsonian Institution to investigate the locality and to consider the availability of this rock for the building of the Smithsonian Institution. Accordingly in the spring of 1847 Dr. David Dale Owen visited these quarries, which, on the whole, he found were worthless for the purpose in hand.

"At the present time the work in the Potomac marbles is carried on almost exclusively by the Washington Junction Stone Co., which quarries both sandstone and Potomac marble. The former is obtained in good size blocks but the latter is wrought almost entirely in small slabs. The marble is taken from a small opening about half a mile southwest of the quarry buildings. The conglomerates under discussion belong in the Newark formation, which extends along the western border of the Piedmont Plateau from Connecticut and New York southward. The development of the Potomac marble within the Newark is not great and there are but few exposures within the state. It

*On the Geology, Mineralogy, Scenery and Curiosities of Parts of Virginia, Tennessee, and the Alabama and Mississippi Territories, etc., with Miscellaneous Remarks, in a letter to the Editor, vol. 1, Amer. Jour. Sci., New Haven, p. 216, 1819.

is sparingly developed north of Frederick, a mile south of Thurmont and only barely represented at Point of Rocks on the eastern slopes of the Catoctin Mountain. According to Mr. Keith* this limestone conglomerate occurs in lenses or wedges in the sandstone ranging from 1 foot to 500 feet in thickness, or possibly even greater. They disappear through complete replacement by sandstone at the same horizon. The wedge may thin out to a feather edge or may be bodily replaced upon its strike by sandstone; one method is perhaps as common as the other.

"The conglomerate is made up of pebbles of limestone of varying size which sometimes reach a foot in diameter, although usually averaging about two or three inches. The fragments, which are both well rounded and angular, range in color from gray to blue and dark blue, and occasionally pebbles of quartz, chloritic schists and white crystalline marble occur. All are embedded in a red calcareous matrix mixed with a greater or less amount of sand. The pebbles are very similar to the magnesian limestone of the Shenandoah formation, developed in the Frederick and Hagerstown valleys and to the rocks of the complex which forms the Catoctin Mountain. Occasionally pebbles show evidences of having been decayed even before they became a part of the conglomeratic mass, but this may be due to their greater solubility, since the matrix does not show a corresponding degree of decomposition.

"The bedding so far as it has been observed is irregular and of little importance in the quarrying of the rock, the lenticular character of the beds having far more importance than the position of the individual pebbles within the mass. In the same way the jointing is also a relatively subordinate feature since the different degrees of cohesion between the parts of the pebbles and that between the pebbles and the matrix play an important part in determining along what planes a rupture will take place. The texture shows a wide variation in the size of the grains, in the character of the material composing them, and in the relative amount of matrix between the grains and pebbles. This wide range in the size of the particles and in their abundance leads to many difficulties in polishing the rocks, but the difference between the hardness of the limestone and that of the quartz pebbles is particularly a source of expense and annoyance, since the hard quartz pebbles break away from the softer parts in which they lie, leaving numerous cavities to be filled with colored wax or shellac. This difference in the hardness and material of the pebbles, together with the conglomeritic character of the mass excludes the use of hammers and chisels. Any satisfactory quarrying of the blocks must be done with saw and abrasive materials. It is this difficulty in the working, together with the fragile nature of the stone itself, which has kept it from the conspicuous place in the market, which its oddity and beauty deserve.

"The chemical composition of breccia can scarcely be determined from a single analysis, and the figures obtained from an average of several analyses may be of little account. The values obtained depend very largely on the accuracy of the analyst, the fineness of the grain, the homogeneity of the specimens and the number of samples taken

*Keith, Arthur, Geology of the Catoctin Belt, 14th Ann. Rept. U. S. Geol. Surv., part II, p. 346, Washington, 1894.

to make an average test. Higgins* gives the following as 'the average of various analyses made of the Breccia marble, or Calico limestone, found in Montgomery, from which the pillars in the House of Representatives at Washington are made:'

Sand, 12.25; Iron and clay, 100; Lime, as carbonate, 70.50; Magnesia, 15.00; Other constituents not worthy of mention, 0.25; Total, 99.00.

"This is probably of little value in itself and should have no weight in estimating the value of the marble. The stone is particularly suited to mosaic work and interior decorations, and should not attempt any competition as a structural material with the stones now in common use.

"The influence of microscopic structures in a stone like this breccia is more than over-balanced by the variations in the larger structural features of the rock. If the microscope or hand lens shows that the stone is sufficiently fine and homogeneous to take a good polish with few minute irregularities on the surface that is sufficient, still experience clearly shows that this rock will take a good polish and that it will withstand any pressure to which it may be subjected as an ornamental or decorative stone.

"This unique material deserves to be fully exploited and pushed as a novelty in the highest class of interior furnishings. It is believed that a demand might be created for this stone in some of the best work which is done in New York, Philadelphia, Washington and other large cities, where there is a call for materials which are suitable for floors and other interior decorations, striking in color and texture and of pleasing contrasts."

*Second Rept. Jas. Higgins, State Agr. Chemist, Annapolis, 1852, p. 39.

CHAPTER VIII

PRODUCTION STATISTICS

The following tables giving production statistics have been compiled from the annual reports on Mineral Resources of the United States, formerly collected and published by the United States Geoglogical Survey, but in recent years by the United States Bureau of Mines. They are the most accurate figures obtainable, nevertheless they are admittedly incomplete because many companies, mainly the smaller producers, are negligent in reporting their output and in numerous cases have never received any request from the Government for such figures. It is manifestly impossible for the authorities to learn of all the limestone operations in as large a State as Pennsylvania where many quarries are worked for only short periods or intermittently. The figures are therefore lower than the actual production.

It would be of interest to have the complete production statistics for the State but unfortunately such information is lacking for the earlier years and for other periods is so generalized or incomplete that its value is slight.

Limestone sold in Pennsylvania and in the United States, 1910-1930.

		Number of active plants	BUILDING										CRUSHED STONE			
			Rough Construction		Rough Architectural		Dressed		Rubble		Riprap		Concrete and road metal		Railroad Ballast	
			Short tons	Value	Cubic feet	Value	Cubic feet	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
1910	Pa.					$103,295		$118		$3,314		$1,714		$844,944		$495,002
	U.S.					2,276,574		2,995,450		820,002		1,348,172		11,376,931		4,288,431
1911	Pa.					89,798		4,545		6,595		4,201		1,070,509		390,938
	U.S.					1,997,757		2,724,043		640,308		1,561,273		11,928,385		4,619,972
1912	Pa.					144,424		1,258		8,730		1,745		897,787		285,312
	U.S.					2,178,870		2,873,026		639,674		1,182,451		12,765,298		4,854,301
1913	Pa.					106,690		840		8,600		8,391		1,086,893		419,579
	U.S.					1,943,064		2,566,275		440,480		1,331,423		13,520,809		5,551,415
1914	Pa.					67,869		1,215		6,970		2,436		1,071,887		291,977
	U.S.					1,642,627		2,254,227		423,336		1,123,123		14,094,533		3,967,348
1915	Pa.					49,150		695		4,637		2,057		1,053,814		172,708
	U.S.					1,488,945		2,567,256		306,116		1,305,636		13,498,739		3,604,256
1916	Pa.					44,946		(a)		(a)		4,824		916,959		111,202
	U.S.					1,305,771		3,282,434		297,772		1,357,457		14,067,631		3,650,647
1917	Pa.					54,207		(a)		(a)		5,637		998,938		114,650
	U.S.					2,083,886		2,031,480	277,376	270,327	1,007,357	18,679,213		14,146,603		3,394,495
1918	Pa.				303,343	37,054			1,743	1,792	(a)	(a)	719,286	942,539	86,737	74,361
	U.S.				2,561,600	943,735	1,136,435	1,322,919	106,327	109,369	1,118,109	969,276	13,610,947	12,371,502	5,509,911	3,901,682
1919	Pa.	241							36,771	59,630	4,944	9,488	1,660,402	2,228,902	181,383	185,976
	U.S.	1,192			4,006,620	2,184,891	1,470,600	2,073,445	328,295	430,113	833,622	908,595	16,956,886	17,887,168	4,805,060	3,822,038
1920	Pa.	267			222,240	41,901			7,760	14,012	8,640	10,651	1,879,750	2,989,994	124,590	207,993
	U.S.	1,269			5,955,320	4,239,912	1,586,830	3,957,954	274,630	425,279	892,610	907,616	20,419,130	25,349,446	5,388,670	5,350,353
1921	Pa.	279	24,540	$40,390							(a)	(a)	2,392,110	3,463,572	99,410	139,371
	U.S.	1,251	183,000	253,786	2,458,780	1,699,783	3,407,920	5,933,017	188,000	280,067	941,730	1,003,399	23,985,790	27,903,303	4,734,620	4,329,135
1922	Pa.	279	36,040	50,709					(a)	(a)			2,874,090	3,364,085	114,070	142,525
	U.S.	1,292	210,690	271,343	4,352,030	2,577,416	5,843,550	9,570,114	286,340	470,264	1,010,850	925,760	27,906,450	28,966,511	4,879,850	4,258,368
1923	Pa.	280	29,160	38,648					2,300	2,903			3,007,310	4,231,112	64,590	73,756
	U.S.	1,437	210,310	238,805	5,031,840	3,184,932	7,192,810	12,797,358	327,180	484,771	1,536,570	1,451,670	33,382,210	35,925,709	8,004,340	6,615,045
1924	Pa.	265	22,490	32,381					1,590	1,777			3,637,920	5,013,677	77,210	95,624
	U.S.	1,358	239,680	304,911	5,012,520	3,231,613	6,751,930	12,269,156	392,180	623,844	1,695,280	1,513,443	39,213,110	41,911,051	7,233,570	5,683,386
1925	Pa.	262	22,440	32,206									3,954,560	5,213,328	85,410	98,322
	U.S.	1,422	270,970	335,842	5,728,830	3,661,276	7,168,070	12,094,961	324,630	513,387	1,847,330	1,406,714	41,800,470	44,966,391	9,537,370	7,479,719
1926	Pa.	251	22,730	34,616									3,830,210	4,879,478	137,540	149,578
	U.S.	1,385	288,760	380,131	6,161,890	3,837,081	9,015,090	16,174,385	254,240	476,545	1,815,550	1,898,951	45,237,350	48,650,616	11,029,690	8,785,563

Limestone sold in Pennsylvania and the United States (Cont'd.)

			BUILDING										CRUSHED STONE			
		Number of active plants	Rough Construction		Rough Architectural		Dressed		Rubble		Riprap		Concrete and road metal		Railroad Ballast	
			Short tons	Value	Cubic feet	Value	Cubic feet	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
1927	Pa.	246	29,950	48,452	------	------	------	------	9,660	13,242	3,500	5,300	4,083,750	5,897,498	69,220	72,693
	U.S.	1,446	206,480	292,792	5,953,780	3,832,414	8,811,110	14,694,839	226,280	400,790	2,185,380	2,119,557	53,750,130	54,638,975	11,330,270	8,772,490
1928	Pa.	223	80,700	101,196	------	------	------	------	------	------	2,700	2,700	4,883,090	5,901,807	74,560	81,590
	U.S.	1,258	211,780	278,434	5,255,690	3,268,140	10,655,180	16,646,389	365,920	705,723	1,822,340	1,765,147	49,075,720	50,490,370	11,876,780	8,803,777
1929	Pa.	223	64,140	87,044	------	------	------	------	------	------	------	------	5,277,580	6,127,843	50,570	47,059
	U.S.	1,459	178,490	280,564	6,192,550	3,779,639	9,430,100	16,589,054	352,480	693,678	2,080,580	2,655,374	50,090,350	50,057,122	11,374,850	8,877,328
1930	Pa.	219	31,950	40,699	------	------	------	------	------	------	------	------	5,933,020	6,978,970	145,210	145,756
	U.S.	1,436	131,410	194,550	6,134,250	3,278,346	7,936,770	15,062,397	756,470	623,100	2,918,110	3,318,084	48,213,300	47,788,979	8,561,760	6,365,338

(a) Statistics for Pennsylvania not published separately on account of few producers.

Limestone sold in Pennsylvania and in the United States, 1910-1930. (Continued.)

		Fluxing stone		Sugar factories		Glass factories		Paper mills		Agriculture		Other		Total	
		Long tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons (approximate)	Value
1910	Pa.	7,545,094	$3,735,060										$121,137		$5,394,611
	U.S.	18,203,882	9,345,733		362,400								1,122,560		34,603,678
1911	Pa.	6,769,949	3,396,304										152,160		5,243,045
	U.S.	16,126,650	7,987,208		300,717								1,474,379		33,897,612
1912	Pa.	8,510 211	4,361,677										165,831		6,017,308
	U.S.	20,190,554	9,937,772		335,108								1,516,962		36,729,800
1913	Pa.	8,180,056	4,206,797								51,416		137,244		6,189,145
	U.S.	22,620,961	11,103,989		387,724						493,718		1,051,062		38,745,429
1914	Pa.	6,467,961	3,563,571								72,789		97,054		5,270,458
	U.S.	15,298,756	7,890,369		323,796						688,961		1,158,525		33,894,155
1915	Pa.	8,625,636	4,799,546								117,903		164,977		6,367,446
	U.S.	18,998,723	9,672,347		381,038						893,530		1,404,434		35,229,866
1916	Pa.	10,019,046	6,768,374				74,990			73.301	129,574		115,219		8,167,639
	U.S.	26,623,508	13,946,882	369,028	369,694	193,028	181,322			1,043,876	1,109,208		1,639,639		41,319,871
1917	Pa.	9,840,305	8,790,058				109,862		(a)	138,323	261,396		234,449		10,589,524
	U.S.	25,574,146	18,679,213	530,612	666,138	293,152	344,479	101,305	95,582	1,040,248	1,352,397		2,276,323		46,263,379
1918	Pa.	8,689,007	10,473,227			51,185	93,653	29,404	36,670	131,061	325,982	258,562	326,284		12,302,255
	U.S.	23,862,029	23,427,736	435,555	649,589	202,211	332,744	100,247	117,829	1,091,918	1,626,292	4,653,699	3,642,497		49,453,006
1919	Pa.	7,607,131	9,547,016			53,509	100,316	(a)	(a)	65,612	243,529	122,002	229,843	10,665,500	12,640,411
	U.S.	18,928,886	19,271,674	503,835	821,912	166,106	278,467	92,421	129,649	1,392,914	2,409,460	3,080,101	2,909,791	49,759,800	53,171,701
1920	Pa.	8,228,970	11,967,561			67,690	158,626	(a)	(a)	70,710	281,196	112,910	203,642	11,531,540	15,913,109
	U.S.	22,301,060	26,475,763	637,090	1,200,394	196,150	400,873	139,880	256,278	1,364,260	2,724,209	4,432,170	4,435,342	59,290,000	75,655,260
1921	Pa.	3,510,780	4,041,152			49,570	110,351	(a)	(a)	97,090	333,354	102,320	196,138	6,713,240	8,346,138
	U.S.	9,503,830	9,428,767	570,840	1,019,288	118,970	232,715	120,460	223,601	1,311,520	2,355,339	2,383,280	3,087,394	45,621,000	57,749,594
1922	Pa.	5,699,180	5,569,056			63,950	126,244	22,790	28,344	110,390	339,761	131,710	227,266	9,736,470	9,848,290
	U.S.	16,687,740	14,208,457	371,430	634,511	166,070	291,854	149,430	264,130	1,195,000	2,150,435	3,317,430	3,808,764	58,928,660	68,397,927
1923	Pa.	9,037,150	8,616,237			62,440	114,342	27,280	35,868	95,170	329,210	233,150	311,017	12,558,550	13,753,093
	U.S.	22,823,340	20,333,939	474,530	875,774	197,380	301,403	206,740	326,054	1,278,770	2,160,249	4,625,510	4,877,468	76,701,360	89,620,007
1924	Pa.	7,366,840	6,854,473			53,720	95,677	29,170	37,312	72,430	275,974	296,740	371,717	11,558,110	12,778,612
	U.S.	19,683,150	15,827,464	618,230	1,055,505	177,260	286,164	138,280	236,834	1,352,660	2,046,860	4,293,240	4,878,725	75,894,430	89,868,956
1925	Pa.	8,465,170	7,294,409			55,140	92,729	29,840	38,234	102,710	399,053	317,990	459,490	13,033,880	13,630,050
	U.S.	22,840,500	17,318,366	471,580	796,974	324,160	412,832	109,730	198,691	1,954,480	2,880,580	5,234,640	5,942,286	85,649,440	98,008,028
1926	Pa.	8,694,870	7,371,706			81,880	130,467	30,350	37,885	78,150	307,847	374,560	535,794	13,250,290	13,447,371
	U.S.	23,849,700	18,021,449	416,920	771,488	326,280	543,163	202,460	319,998	1,850,620	3,064,235	5,510,870	0,328,694	91,887,900	109,252,299

Limestone sold in Pennsylvania and in the United States 1910-1930 (cont.)

		Fluxing stone		Sugar factories		Glass factories		Paper mills		Agriculture		Other		Total	
		Long tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons (approximate)	Value
1927	Pa.	6,979,280	5,867,110	----------	----------	84,470	167,910	32,110	38,221	65,930	239,256	424,200	676,181	12,382,070	12,025,863
	U.S.	21,660,820	15,977,484	483,800	881,370	247,210	420,415	289,010	436,204	2,206,470	3,360,704	6,004,180	6,611,790	99,662,270	112,439,824
1928	Pa.	7,459,710	5,991,367	----------	----------	105,230	179,914	30,560	35,400	55,470	182,624	356,100	598,568	12,048,120	12,075,166
	U.S.	23,094,090	16,929,986	487,060	851,850	281,260	441,260	155,050	290,590	2,185,870	3,155,848	6,148,620	6,004,814	96,964,650	110,231,974
1929	Pa.	8,621,270	6,721,767	----------	----------	98,560	177,838	30,650	35,015	67,910	221,083	314,400	606,638	14,525,080	14,024,287
	U.S.	24,337,280	17,994,110	487,990	874,909	257,370	455,367	273,880	456,251	2,654,580	3,764,775	7,464,780	7,427,900	100,686,960	113,906,071
1930	Pa.	5,483,150	4,198,246	----------	----------	46,810	79,090	(a)	(a)	82,900	241,206	349,480	649,373	12,100,700	12,375,067
	U.S.	17,021,350	12,312,602	414,340	733,359	224,180	349,771	248,790	377,059	2,542,100	3,309,329	6,688,260	6,289,200	88,741,440	100,002,114

(a) Statistics for Pennsylvania not published separately on account of few producers.

Hydrated lime sold in Pennsylvania and in the United States, 1910-1930.

		Short Tons	Value
1910	Pa.	----------	----------
	U.S.	320,819	$1,288,789
1911	Pa.	----------	----------
	U.S.	304,593	1,372,057
1912	Pa.	----------	----------
	U.S.	416,890	1,829,064
1913	Pa.	----------	----------
	U.S.	493,269	2,205,657
1914	Pa.	----------	----------
	U.S.	515,121	2,239,916
1915	Pa.	----------	----------
	U.S.	581,114	2,457,602
1916	Pa.	126,890	585,847
	U.S.	717,382	3,62[illegible]988
1917	Pa.	142,254	974,936
	U.S.	709,157	4,643,004
1918	Pa.	133,583	1,126,957
	U.S.	620,216	5,342,113
1919	Pa.	166,282	1,607,090
	U.S.	777,408	7,061,146
1920	Pa.	169,639	1,884,787
	U.S.	853,116	9,287,562
1921	Pa.	135,917	1,311,678
	U.S.	792,970	7,421,637
1922	Pa.	172,179	1,571,709
	U.S.	1,106,063	9,868,980
1923	Pa.	177,836	1,740,209
	U.S.	1,225,928	12,229,598
1924	Pa.	189,431	1,727,[illegible]49
	U.S.	1,316,664	13,199,846
1925	Pa.	219,737	2,020,337
	U.S.	1,560,848	15,287,461
1926	Pa.	237,066	2,061,741
	U.S.	1,606,811	15,182,460
1927	Pa.	264,491	2,147,828
	U.S.	1,596,906	14,581,695
1928	Pa.	2[illegible]3,973	2,185,386
	U.S.	1,612,818	13,540,215
1929	Pa.	259,251	2,232,117
	U.S.	1,550,771	12,771,525
1930	Pa.	234,192	1,904,179
	U.S.	1,329,562	10,357,445

Lime consumed in Pennsylvania and in the United States, in short tons, 1916-1924.

					Consumption			
		Sales	Shipments from State	Shipments into State	Quick lime	Hydrated lime	Total	Per capita (estimated)
1916	Pa.	972,343	229,785	267,029	----------	----------	1,009,587	.12
	U.S.	4,073,433	2,063,213	2,050,876	----------	----------	4,061,096	.04
1917	Pa.	936,209	238,960	200,932	762,837	135,344	898,181	.10
	U.S.	3,786,364	1,794,189	1,784,707	3,068,838	708,044	3,776,882	.037
1918	Pa.	801,834	239,832	209,845	633.124	138,723	771,847	.085
	U.S.	3,206,016	1,566,616	1,553,959	2,574,872	618,487	3,193,359	.030
1919	Pa.	779,608	237,928	168,284	571,088	138,876	709,964	.081
	U.S.	3,330,347	1,529,001	1,524,613	2,550,162	775,797	3,325,959	.031
1920	Pa.	784,083	269,876	172,994	542,789	144,412	687,201	.078
	U.S.	3,570,141	1,704,741	1,700,034	2,713,544	851,890	3,565,434	.033
1921	Pa.	467,794	108,691	107,494	353,565	113,032	466,597	.05
	U.S.	2,453,313	1,238,866	1,236,464	1,698,805	752,106	2,450,911	.022
1922	Pa.	719,536	251,753	222,873	533,509	157,147	690,656	.076
	U.S.	3,639,617	2,043,754	2,037,939	2,530,967	1,102,835	3,633,802	.033
1923	Pa.				566,504	169,005	735,507	.08
	U.S.	4,076,243	2,221,660	2,213,807	2,844,969	1,223,421	4,068,390	.036
1924	Pa.	700,380	239,755	250,698	519,339	191,984	711,323	----
	U.S.	4,072,000	2,356,355	2,348,520	2,750,273	1,313,892	4,064,165	----

Portland cement produced in Pennsylvania and in the United States, 1910-1930.

		Active Plants	Production	Shipments		
			Barrels	Barrels	Value	Av. factory price per barrel
1910	Pa.	25	26,675,978	----------	$19,551,268	$0.729
	U.S.	111	76,549,951	----------	68,205,800	.891
1911	Pa.	25	26,864,679	----------	19,258,253	.715
	U.S.	115	78,528,637	----------	66,248,817	.844
1912	Pa.	23	26,441,338	27,539,076	18,918,165	.687
	U.S.	110	82,438,096	85,012,556	69,109,800	.813
1913	Pa.	23	28,701,845	28,060,495	24,268,800	.865
	U.S.	113	92,097,131	88,689,377	89,106,975	1.005
1914	Pa.	20	26,570,151	25,985,106	20,944,787	.806
	U.S.	110	88,230,170	86,437,956	80,118,475	.927
1915	Pa.	20	28,648,941	28,188,450	20,252,961	.718
	U.S.	106	85,914,907	86,891,681	74,756,674	.860
1916	Pa.	20	27,323,147	28,748,546	27,915,298	.971
	U.S.	113	91,521,198	94,552,296	104,258,216	1.103
1917	Pa.	21	27,752,828	27,709,442	34,512,388	1.25
	U.S.	117	92,814,202	90,703,474	122,775,088	1.35
1918	Pa.	21	22,628,901	22,238,689	33,600,956	1.51
	U.S.	114	71,081,663	70,915,508	113,153,513	1.60
1919	Pa.	21	25,325,173	26,250,077	43,126,528	1.64
	U.S.	111	80,777,935	85,612,899	146,734,814	1.71
1920	Pa.	21	28,269,314	27,662,116	52,632,082	1.90
	U.S.	117	100,023,245	96,311,719	194,439,025	2.02
1921	Pa.	22	27,628,598	26,622,367	46,881,625	1.76
	U.S.	115	98,842,049	95,507,147	180,778,415	1.89
1922	Pa.	22	33,276,093	34,023,695	55,528,002	1.63
	U.S.	118	114,789,984	117,701,216	207,170,430	1.76
1923	Pa.	22	38,157,482	38,610,852	69,792,343	1.81
	U.S.	126	137,460.238	135,912,118	257,684,424	1.90
1924	Pa.	22	40,849,602	40,208,860	69,693,517	1.73
	U.S.	132	149,358,109	146,047,549	264,046,708	1.81
1925	Pa.	22	42,346,830	41,899,787	72,870,981	1.74
	U.S.	138	161,658,901	157,295,212	278,524,108	1.77
1926	Pa.	23	42,865,694	41,395,604	70,437,218	1.70
	U.S.	140	164,530,170	162,187,090	277,965,473	1.71
1927	Pa.	25	43,732,278	42,909,513	66,711,069	1.55
	U.S.	153	173,206,513	171,864,728	278,854,647	1.62
1928	Pa.	26	41,522,401	41,161,019	62,572,588	1.52
	U.S.	156	176,298,846	175,838,332	275,972,945	1.57
1929	Pa.	27	39,354,470	39,309,662	55,600,953	1.41
	U.S.	163	170,646,036	169,868,322	252,153,789	1.48
1930	Pa.	27	37,843,662	37,968,647	52,712,176	1.39
	U.S.	163	161,197,228	159,059,334	228,779,756	1.44

Lime sold by producers in Pennsylvania and in the United States, 1915-1930.

		Number of plants	Building		Agriculture		Chemical Uses			
							Glass works		Paper mills	
			Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
1915	Pa.	451	284,239	$1,049,135	345,960	$995,703	----------	----------	50,657	165,135
	U.S.	905	1,136,696	4,812,710	653,686	2,163,874	----------	----------	216,819	782,366
1916	Pa.	335	212,095	962,266	318,722	1,036,222	----------	----------	69,474	245,601
	U.S.	778	1,509,958	7,859,614	613,527	2,224,401	----------	----------	353,187	1,461,412
1917	Pa.	222	162,658	1,034,504	246,608	1,218,316	9,954	$58,707	78,181	377,933
	U.S.	595	1,313,493	8,713,845	488,297	2,475,731	60,624	316,280	355,768	2,008,433
1918	Pa.	162	126,432	1,020,744	200,073	1,243,636	1,281	7,675	77,512	527,313
	U.S.	496	914,186	7,781,388	391,047	2,098,848	34,051	265,855	325,172	2,610,645
1919	Pa.	187	165,906	1,571,238	232,831	1,706,027	3,986	29,618	73,761	537,691
	U.S.	537	1,191,434	11,484,318	438,632	3,345,039	44,618	336,020	335,813	2,836,347
1920	Pa.	162	148,378	1,625,471	202,830	1,792,948	4,242	40,802	56,572	506,578
	U.S.	515	1,305,412	15,269,683	351,851	3,096,705	54,747	551,945	365,897	3,544,084
1921	Pa.	183	137,139	1,261,494	152,667	1,183,361	2,690	21,734	46,977	390,334
	U.S.	520	1,239,486	13,258,443	284,722	2,237,510	43,851	367,796	235,855	2,207,938
1922	Pa.	177	233,088	1,920,087	137,460	1,021,092	(a)	(a)	55,144	414,491
	U.S.	530	1,845,208	18,463,825	272,726	2,005,082	62,187	463,628	310,229	2,683,487
1923	Pa.	143	287,595	2,563,641	112,011	838,010	1,361	12,492	36,239	287,108
	U.S.	467	2,131,533	22,521,638	240,551	1,825,519	78,942	676,291	311,309	2,768,909
1924	Pa.	136	288,899	2,500,901	116,966	883,225	602	3,809	39,799	310,777
	U.S.	450	2,169,700	23,011,935	248,338	1,864,514	72,822	622,456	300,101	2,528,242
1925	Pa.	142	314,333	2,786,158	129,834	958,411	(1)	(1)	54,149	401,574
	U.S.	450	2,387,267	24,115,420	298,976	2,129,169	73,011	622,909	376,670	3,174,851
1926	Pa.	133	290,704	2,401,496	128,881	978,323	(1)	(1)	63,971	522,454
	U.S.	435	2,320,323	23,227,034	297,010	2,153,233	84,263	713,321	423,322	3,492,996
1927	Pa.	122	273,750	2,259,108	147,975	1,063,842	739	6,133	46,525	337,865
	U.S.	417	2,148,840	20,962,759	322,893	2,237,871	78,994	665,026	429,606	3,413,030
1928	Pa.	130	251,056	1,964,044	154,777	1,133,190	(1)	(1)	47,686	329,118
	U.S.	411	1,986,465	17,706,420	333,910	2,287,558	76,161	588,305	429,334	3,260,733
1929	Pa.	116	170,926	1,453,556	160,856	1,257,687	(1)	(1)	43,216	313,271
	U.S.	381	1,640,827	14,303,539	338,329	2,387,901	75,283	544,760	411,017	3,057,350
1930	Pa.	115	113,693	928,896	164,747	1,226,000	2,930	22,220	39,327	278,420
	U.S.	375	1,204,614	10,050,270	343,111	2,372,779	62,912	408,429	378,721	2,652,232

Lime sold by producers in Pennsylvania and in the United States, 1915-1930.

	Chemical Uses								Total	
	Sugar Refineries		Tanneries		Metallurgy		Other chemical uses			
	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
1915 Pa.	--------	--------	11,804	$38,373	--------	--------	107,407	$344,201	901,549	$2,947,058
U.S.	--------	--------	47,104	190,864	--------	--------	492,870	1,653,750	3,589,699	14,336,756
1916 Pa.	--------	--------	17,757	70,955	56,404	$197,436	131,201	451,759	972,343	3,857,553
U.S.	--------	--------	59,919	278,003	180,018	712,101	621,120	2,298,246	[illegible]	[illegible]
1917 Pa.	--------	--------	24,236	138,305	90,688	445,609	129,791	705,594	936,209	5,900,016
U.S.	--------	--------	66,629	408,976	209,976	1,141,647	772,787	4,476,191	3,786,364	23,807,877
1918 Pa.	--------	--------	26,006	196,791	87,327	599,13[illegible]	84,562	595,152	801,834	6,654,407
U.S.	--------	--------	74,350	637,960	253,778	1,884,672	566,532	4,177,302	3,206,076	26,808,909
1919 Pa.	--------	--------	11,416	88,629	84,489	530,923	204,210	1,696,659	779,608	6,181,710
U.S.	--------	--------	59,978	580,022	295,622	2,152,554	861,022	7,595,818	3,330,347	29,448,553
1920 Pa.	--------	--------	21,245	198,706	89,689	675,529	260,140	2,669,800	784,083	7,519,147
U.S.	--------	--------	61,162	668,999	344,921	2,836,474	1,000,550	10,304,049	3,570,141	37,543,840
1921 Pa.	--------	--------	6,003	50,073	59,572	432,897	103,737	898,882	509,891	4,247,509
U.S.	--------	--------	47,841	481,372	164,245	1,232,748	456,087	4,372,991	2,532,153	24,895,370
1922 Pa.	--------	--------	4,552	34,243	79,757	522,769	208,213	1,658,576	719,53[illegible]	5,581,794
U.S.	--------	--------	42,978	420,148	200,799	1,458,553	834,279	6,986,366	3,639,61[illegible]	33,255.039
1923 Pa.	--------	--------	8,195	68,066	133,288	954,645	194,150	1,648,770	772,839	6,372,732
U.S.	--------	--------	53,906	523,994	373,020	3,044,383	886,982	8,632,918	4,076,243	39,993,652
1924 Pa.	374	3,179	9,995	84,479	70,462	431,873	173,283	1,416,563	700,380	5,634,806
U.S.	17,061	246,179	53,349	515,133	336,813	2,727,518	873,818	8,080,546	4,072,000	39,596,423
1925 Pa.	(1)	(1)	15,184	126,005	75.832	461,716	204,556	1,681,875	794,951	6,425,675
U.S.	19,089	280,985	62,933	557,187	411,190	3,007,228	951,687	8,721,392	4,580,823	42.609,141
1926 Pa.	301	2,209	20,666	185,267	82,260	497.612	207,413	1,715,951	794,196	6,303,312
U.S.	15,379	238,188	66,536	584,296	408,234	2,860.338	945,331	8,297,046	4,560,398	41,566,452
1927 Pa.	155	1,190	22,277	165,394	88,421	490,016	233,729	1,781,693	813,571	6,105,241
U.S.	16,086	235,555	63,666	501,442	406,063	2,640,658	948,784	7,982,072	4,414,932	38,638.413
1928 Pa.	(1)	(1)	20,912	157,330	117,961	665,415	239,770	1,851,210	834,050	6,119,036
U.S.	22,678	280,186	64,464	494,983	504,248	3,055,081	1,041,152	8,776,369	4,458,412	36,449,635
1929 Pa.	(1)	(1)	22,649	167,850	149,980	833,657	231,481	1,842,066	782,915	5,896,752
U.S.	20,758	249,190	67,046	516,207	578,488	3,258,992	1,138,020	9,160,909	4,269,768	33,478,848
1930 Pa.	78	519	19,222	151,842	121,744	679,362	171,779	1,374,411	633,520	4,661,670
U.S.	18,905	238,788	56,526	438,869	415,692	2,371,222	907,399	7,083,897	3,387,880	25,616,486

PART II

Descriptions of Limestones by Counties

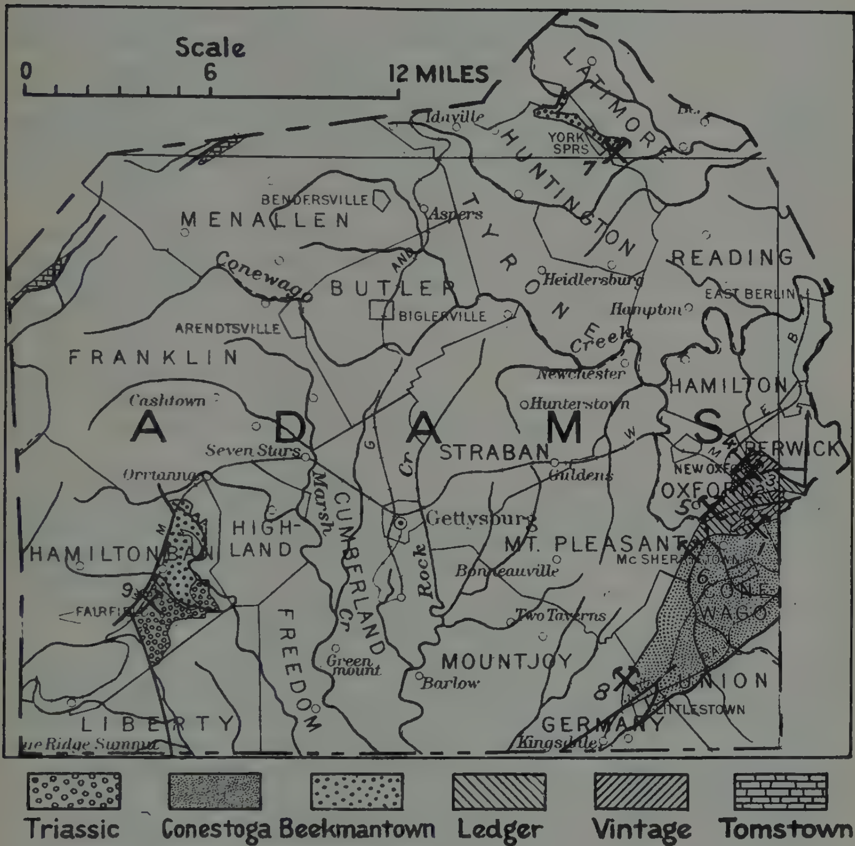

Fig. 1. Limestone areas in Adams County.

1. Max Hoke and Son
2. Steacy and Wilton
3. Bethlehem Mines Corp.
4. Shriver quarry, E. M. Bittinger
5. Adams Stone Products Co.
6. Pullman quarry, Nicholas Gebhardt
7. Gardner quarry, State Highway Department
8. W. V. Sneeringer
9. Fairfield Lime and Stone Co.

PART II

ADAMS COUNTY

The limestones of Adams County are present in several different places but nowhere do they occupy large areas. The most extensive occurrence of limestones is wedge-shaped and tapering from a width of about 3½ miles near Hanover to a point a short distance beyond Littlestown. It is within this section that the chief quarries of the county are located, especially at Bittinger where the Bethlehem Mines Corporation and the Steacy & Wilton Co. operate large quarries. The limestones in this area belong to various formations of the Cambrian and Ordovician periods.

The second most important limestone area of the county extends as a band up to 2¼ miles in width from near Orrtanna to a point about 2½ miles south of Fairfield. In this band about half of the limestones belong to the Ordovician period and the other half to the Triassic.

Also there is a narrow band of Cambrian limestones between Yellow Ridge and Wolf Hill in the extreme northwest corner of the county and a small area of Ordovician limestones in the vicinity of York Springs.

Within these areas there are many small abandoned quarries where stone was once dug for lime burning or to a lesser extent for building stone. Crushed stone has been produced in several places and it appears that any of the limestones of the county might be quarried for this use. In recent years the operations have been confined to the vicinity of Hanover, Littlestown and Fairfield.

The geology and mineral resources of the county have been carefully investigated by George W. Stose of the U. S. Geological Survey and the results published in the Fairfield-Gettysburg Folio of the Federal Survey and in Bulletin C-1 of the Pennsylvania Topographic and Geologic Survey. The quoted descriptions following are taken from these publications.

Stose (3) has given the following stratigraphic column for Adams County†:

	Thickness feet
Triassic	
(Newark Series)	
Gettysburg group. Chiefly red shale and sandstone. At top locally contains a limestone conglomerate	16,000
New Oxford group. Mainly red shale and sandstone	7,000
Unconformity	
Conestoga limestone. Impure blue argillaceous limestone weathering readily to shaly fragments and soil	1,000±
Canadian	
Beekmantown (?) limestone series. Rather pure blue limestone finely laminated with impurities	?

†This column has been arranged to follow the official section of the Pennsylvania Geological Survey although the author prefers the U. S. Geological Survey section which does not include the Canadian System.

Unconformity	
Middle Cambrian	
Waynesboro group. Sandstone and shale at top, blue white limestone and dolomite in middle, and siliceous gray limestone and sandstone at base	1,000±
Lower Cambrian	
Tomstown limestone group.	
Ledger dolomite. Pure coarse gray dolomite and beds of equally blue and white *limestone marble*	2,000±
Kinzers formation. Dark argillaceous shale	50±
Vintage dolomite. Dark dolomite, poorly exposed	500±
Antietam sandstone. Granular sandstone	500-800
Harpers schist. Gray sandy schist and quartzite	1,000±
Chickies group. White vitreous quartzite with conglomerate at base	800±
Weverton sandstone. Gray and purplish feldspathic sandstone and quartz conglomerate	750
Loudoun formation. Arkosic conglomerate and sericite slate	550
Unconformity	
Algonkian	
Metabasalt greenstone. Altered basic lava	1,000±
Aporhyolite. Altered rhyolite lava	1,000±

TOMSTOWN AND VINTAGE DOLOMITES

Tomstown group.—Except in the northwest corner of Adams County, on the northwest side of Yellow Ridge, Stose has subdivided the Tomstown into the Vintage dolomite, Kinzers formation and Ledger dolomite. In the one place where he had not divided it he describes it as follows (4, p. 7)*:

"The few exposures of the Tomstown dolomite, the lowest of the formations of the Shenandoah group give a very incomplete idea of the composition of the formation, showing only coarse glistening gray dolomite. From outcrops in adjacent portions of Franklin County the formation is seen to be composed largely of dolomite and limestone, with considerable shale interbedded in the lower part. The dolomite is mostly gray with some darker-gray streaks, and some of it has a fetid odor. Thin-bedded dark-blue limestone occurs near the middle of the formation. Fine white siliceous sericitic slate or schist interbedded with dolomite is exposed at the base of the formation in old iron pits close to the Antietam sandstone, and some gray shale near the base is similarly exposed in a railroad cut. The uppermost beds of the formation, just beneath the siliceous rock at the base of the Waynesboro formation, are blue, laminated, somewhat magnesian limestone containing a small amount of black chert.

"On account of the relatively soluble character of the formation it forms a depression between South Mountain and an irregular line of low ridges and knobs of the Waynesboro formation farther out in the valley. Its thickness determined near Tomstown, in the Chambersburg quadrangle, is about 1,000 feet."

Vintage dolomite.—"Just above the Antietam sandstone occur light-blue limestone and dolomite mapped as the Vintage dolomite. The

* Numbers in parenthesis refer to bibliography at the end of each chapter.

formation is poorly exposed, as it occupies a lowland deeply covered with soil, only small outcrops being seen on the slopes of ridges of the overlying shale. It is quarried in a few small pits, and the beds seen are thin bedded and impure. The formation is estimated to be 500 feet thick.

"It crops out in only two areas, one east and the other south of Bittinger. Each area lies between hills composed of Antietam sandstone and a semi-circular line of hills of overlying Kinzers shale.

"No fossils have been found in this formation in the area. It occupies the same position as fossiliferous dolomite that lies between Antietam sandstone and a fossiliferous shale in the Kinzers formation in the vicinity of York and Lancaster, to the east, and is undoubtedly to be correlated with that bed. It was named Vintage dolomite from a village in Lancaster County, where the rock is exposed in a cut on the main line of the Pennsylvania Railroad. It is equivalent to the lower part of the Tomstown dolomite."

Stone of this formation was formerly quarried and burned for lime in several places about one mile south of Bittinger, near the Western Maryland Railroad. Two of these quarries once operated have been described by Stose as follows (3, p. 31):

"The Max Hoke and Son quarry is on a short railroad spur 1 mile south of Bittinger station. It is a large pit about 300 feet square and 20 feet deep. Most of the rock is high-calcium white marble and sheared light-gray fine-grained limestone. The north face of the quarry is dark dolomite with lumpy structure, and at the contact the limestone is highly brecciated and veined with calcite, evidently along a fault. Two steam drills were in operation at the time of first visit in 1908, and the quarry was kept dry by a large pump. Tram cars conveyed the rock to the mill, from which a trestle 50 feet high led to three kilns, which are of stone with high smoke stacks. The interbedded dolomite and impure thin-bedded limestone were crushed in a large mill equipped with pan elevators, and after screening out 3 sizes, the pulverized limestone screening was saved for use in making cement blocks. The plant has since shut down and the quarry is full of water. This flooded quarry is now the site of an ice manufacturing plant.

"A quarry just north of the Hoke quarry, newly opened when seen in 1908, had high-grade rock at the surface but it passes into dolomite at shallow depth and was abandoned."

LEDGER DOLOMITE

"The rock (4, p. 8) immediately above the Kinzers formation is a dolomite which is poorly exposed because it crops out in a lowland deeply covered with soil. The few outcrops seen consist of a hard, knotty dark-gray dolomite, similar to the Tomstown dolomite of Cumberland Valley and to some of the beds in the Vintage dolomite. This bed is overlain by pure limestone and dolomite of the Ledger type, which are extensively quarried at Bittinger, at Centennial, and east of Irishtown. In the quarries granular crystalline gray dolomite merges laterally into high-calcium marble, which is mottled blue and white. The white marble is a little more coarsely

crystallized and is irregularly distributed in and merges with the blue. It is apparently the product of recrystallization during metamorphism. The dolomite similarly is apparently a product of dolomitization of the pure limestone. Such an origin accounts for irregular distribution of the pure calcium carbonate rock in the quarries. The total thickness of the pure beds can not be determined. In the Steacy & Wilton quarry, where the bedding is still preserved, a thickness of 300 feet of pure limestone is exposed. The pure upper beds of the formation are limited to three narrow belts—a very narrow winding area extending north from Bittinger, a wider band running southwest from a point near Red Hill School to Irishtown, and a small area at Centennial. The formation as a whole occupies a large part of the limestone area north of Edgegrove and west of Bittinger. Its thickness can not be accurately determined but is estimated to be about 2,000 feet.

"Fossils were found in an impure banded layer just below the high-grade limestone in the Steacy & Wilton qarry. These fossils were the brachiopod *Nisusia festinata* Billings, which indicates Lower Cambrian age and probable equivalence to the upper part of the Tomstown dolomite of Cumberland Valley. The formation is the direct equivalent of the pure dolomite and high-grade limestone of the York and Lancaster area and takes its name from Ledger, a small village east of Lancaster."

The Ledger formation (3, pp. 29-31) "in the vicinity of Bittinger contains thick beds of almost pure calcium carbonate which can be burned to high-calcium lime suitable for building plaster. Beds of dolomite interbedded with the pure limestone are generally quarried for crushed stone. The rock layers in many of the quarries stand nearly vertical, and the depth to which quarrying can be carried economically is not great because the limestone occupies a flat lowland, and water from springs, streams, and rain rapidly accumulates and fills quarries and pits to the ground-water level, which is approximately the general surface of the lowland. On account of the few natural rock outcrops in the lowland it is difficult to find the high-grade limestone, and most of the quarry sites were determined from a few natural exposures, so it is probable that high-grade limestone occurs at many places beneath the cover of soil in areas between the quarries. The surface distribution of the formation which contains the workable beds of high-calcium limestone is indicated on the accompanying map. The outcrops of the limestone are nearly everywhere covered with soil to a depth of several feet, enough to conceal the rocks but in general not so thick as to make the cost of stripping excessive.

"The quarry formerly owned and operated by John R. Bittinger of Hanover but now owned and operated by the Bethlehem Mines Corporation of Bethlehem, Pa., is the largest quarry in the area. The quarry is at the end of a railroad spur northeast of Bittinger station on the Baltimore & Harrisburg division of the Western Maryland Railroad. The large quarry west of the Hanover pike is connected by a tunnel with another east of the road. To the north several large holes about 50 feet deep that were formerly worked are now filled with water. The large quarry opening is about 800 to 1,000

feet in diameter and about 50 feet deep. The newer quarry is about 1,600 feet long, 700 feet wide and 60 feet deep. The stripping is done by steam shovel and dragline excavator and the dirt is carried by train to a distant dump. The rock is drilled by a churn drill and is blasted to the floor of the quarry where it is handled by an electric shovel. Tram cars carry the rock up inclines to the crushers, an Allis-Chalmers gyratory of huge size. A tram car load of 15 to 20 tons does not half fill it. The rock is broken to 5-inch size. Crusher and hoisting equipment are electrically operated. The rock consists of a mixture of blue, fine-grained limestone and white crystalline marble, both high-calcium lime-rock, and granular gray dolomite. These rocks are intricately mixed, the dolomite and the pure limestone being not only closely folded together but apparently they also grade laterally into each other. The white marble is apparently a more crystalline form of the blue limestone, and they blend into each other irregularly. On account of these lateral changes of character, the bedding is difficult to determine, but the general strike appears to be N65°E. and dip 75°SE." High calcium rock seems to be largely replaced by dolomite in the northern part of the quarry. Typical analyses of the two common types of stone in the quarry are as follows:

Analyses of dolomite and limestone in the Bittinger Quarry of the Bethlehem Mines Corp.

$CaCO_3$	55.00	85.00
$MgCO_3$	41.50	12.00
$Al_2O_3+Fe_2O_3$	1.50	0.90
SiO_2	2.00	2.10

The rock is strongly jointed by planes that strike N.25°E. and dip 80°SE. When operated by John Bittinger, the high calcium limestone was burned to lime and shipped to eastern cities for use in paper manufacture and for building purposes. Eight kilns were in operation in two sets of 4 each, one set charged with alternate layers of fuel and limestone, the other set burned by flame from separate coal furnaces. The Bethlehem Mines Corporation has abandoned the kilns and ships the rock for flux to its own iron furnaces at Bethlehem. The light-colored dolomite which is quarried with the high grade rock is crushed, screened, and sized for road material and railroad ballast. The limestone dust is saved and mixed with screenings as a top dressing for roads. The Bethlehem Company has erected large elevated bins from which the rock is delivered by gravity into freight cars on the siding. Well kept lawn and flower beds are an unusual setting for the crusher and bunker houses.

The estimated annual capacity is 450,000 tons of fluxing stone and 125,000 tons of commercial stone. From 1917, when the property was acquired by the present corporation, to 1930 the quarry has produced 5,770,000 tons of fluxing stone and 522,000 tons of commercial stone.

"Steacy and Wilton of Hanover and Wrightsville, Pa., have a large plant at Bittinger Station. A large new quarry has been opened west of the old quarry which was over 30 feet deep when abandoned and is now full of water, although its walls are largely of high-grade

rocks. The new quarry is about 600 feet in diameter and 65 feet deep. It is largely in granular white marble irregularly mixed with dark and light blue and dull-gray fine-grained limestone, both high-calcium limestones. This high-grade rock is said to run 99.5 per cent $CaCO_3$. Dark-blue to gray dolomite borders the pure rock on the north and apparently also on the south. At the west end of the quarry the bedding of the dolomite is clearly shown by bands of impure limestone which strike N. 60°E. and dip 70°NW. Dolomite also occurs on the southeast wall of the quarry and extends into the southwest wall of the old quarry. The reddish yellow clay overburden is said to average 15 to 18 feet. Pockets of considerable size run down as much as 30 feet and small ones still deeper. Considerable clay comes down with the stone so that it must all be hand loaded. Besides four old stone kilns that are still used, two modern steel kilns are in operation. The high-grade lime produced is used for finishing wall plaster and in paper manufacture. Some discolored lime is sold for fertilizer. The pure rock is also sold for flux. The small sizes and the more impure stone are crushed for road metal. This firm was employing 70 men in July, 1924, and could produce 300 tons of crushed stone daily with a Champion No. 5 and Traylor 18 by 24-inch jaw crusher. Four-flame kilns and six pot kilns are burning agricultural, building and chemical lime. A Clyde hydrator yields about 45 tons of hydrated lime daily."

The Adams Stone Products Co. opened a quarry about 1½ miles west of Bittinger in July, 1929, to obtain crushed stone for highway construction and pulverized limestone for fertilizing purposes. When visited in 1930, the quarry was about 150 feet long, 75 feet wide and the face about 18 feet in height. There are several varieties of stone in the quarry. Most of it is a high grade light-colored marble showing some mottling and pinkish stains. At one side of the quarry there is some dark-blue, high-magnesian stone. The extent of the good stone is indeterminate. The beds strike N.26°E. and dip 79°NW. The clay overburden averages about 10 feet. Triassic red shale formerly covered the whole area and caused the pink stains. Some of it is still present over part of the quarry and elsewhere it fills old solution cavities and joints in the underlying limestone. The principal product is crushed stone. The capacity is reported as 600 tons daily. It is crushed by primary and secondary gyratory crushers. The stone is pulverized for soil fertilizer by a Pennsylvania hammer mill to pass through a 40-mesh screen. An analysis of a composite sample of the best stone furnished by the company is as follows: CaO 49.88, $CaCO_3$ 88.98, MgO 5.09, $MgCO_3$ 10.64, Insol. .89.

"One mile north of Bittinger (3, pp. 32-33) on the Hanover road is the Shriver quarry. At the time of visit in 1908 it was operated by Jacob G. Shriver. Quarrying was done with a steam drill and the plant consisted of three stone kilns and a rock crusher. Mr. Shriver was succeeded by J. H. Maul & Sons of Hanover, and more recently E. M. Bittinger of Hanover operated the quarry for 5 years for crushed stone. In 1924 about 10 men were employed at this quarry. The high-grade white marble and gray limestone are limited to the north face, the larger part of the quarry being composed of dolomite and impure limestone. The contact strikes N. 20°-50°E. and dips 60°NW. Two old abandoned holes are adjacent to the active quarry.

"Numerous old quarries from which the pure limestone has been removed to considerable depth are abandoned and full of water, although high-grade rock is still exposed in the walls of many of them and probably extends under the adjacent lowlands. The impure limestone and dolomite in these old quarries were generally untouched, as in earlier days there was not sufficient demand for crushed stone to warrant quarrying them, and the layers of these impure rocks stand up as high pinnacles and walls in the abandoned flooded quarries.

"Several quarries more than a mile west of Bittinger were operated spasmodically and produced chiefly agricultural lime that was used on the adjacent shale lands to the west. The beds are vertical and the impure rock is left standing as walls between the quarry trenches. Some high-grade limestone is still exposed in the quarry faces. In the vicinity of Centennial, 2 miles west of McSherrystown, there are several large quarries from which large quantities of agricultural lime and broken stone have been obtained. The largest of these, the Pullman quarry, is just west of the village. It was operated by the Centennial Lime & Stone Co. before 1910, and later by E. M. Bittinger, but has been idle since 1916. It is a long, narrow quarry that follows the purer limestone beds, which are about 100 feet thick and strike S. 25°W. and dip 60°NW. Pure light-blue limestone banded with dark layers is the chief rock quarried. Some of these beds are oolitic, others are finely conglomeratic, and some are highly brecciated and veined with coarsely crystalline white calcite. There are also white saccharoidal marble beds 20 to 30 feet thick. These pure beds are probably at the same horizon as those around Bittinger, although they differ somewhat in appearance. The lime that was burned in the three stone kilns was largely used for fertilizer on the Triassic shale lands to the west. Another large quarry in similar rock just west of the Pullman quarry was operated by Harry Strine. Nicholas Gebhardt has more recently produced both crushed stone and lime from the Pullman quarry and another quarry just north of the public road."

"Limestone was also quarried at several places near York Springs. The Gardner quarry, ½ mile east of York Springs, was operated in 1907 by Horace Smith, and more recently by the State Highway Department. Massive beds of white, gray, and pink crystalline marble were quarried, some of which were brecciated. It is overlain by Triassic red sandstone with limestone conglomerate at the base, and is stained pink from the red sediments. This quarry has been idle for several years.

"Judge Geo. H. Trostel quarry is 2 miles northwest of York Springs on the road to Idaville. It is in a field on the north side of the road, has a face about 25 feet high and 300 feet long, but has not been worked in 14 years.

"The Emanuel Menges quarry is near the road crossing southeast of Snyders Hill and 2½ miles northwest of York Springs. The quarry is about 50 yards in diameter and has been idle so long that it is now completely overgrown.

"Both these quarries are in massive light-gray magnesian limestone. Some of the rock is a brecciated white marble cemented by green limestone, and makes a handsome ornamental stone when polished. The limestone is overlain by red Triassic sandstone and intruded by diabase.

"Two other quarries are about 2 miles northwest of York Springs on the Carlisle pike. The Lears quarry was operated for making building lime but has long been idle. The rock is a massive crystalline limestone with fine black seams. The Bushey quarry has more impure rock, is streaked with dark slickensided layers, and veined with green. It is intruded by diabase. The face is 110 feet long and 40 feet high. The rock is closely and irregularly jointed and was burned for lime many years ago in a crude kiln, the ruins of which are near. A stone crusher outfit was brought to this quarry in the spring of 1924 preparatory to producing road metal."

CONESTOGA AND BEEKMANTOWN LIMESTONES

Conestoga limestone.—"The Conestoga limestone (4, p. 8) is an impure blue limestone that occupies the lowland about McSherrystown. Few outcrops of the limestone can be seen, as the formation weathers readily to deep yellow sandy clay soil containing many small fragments of quartz and shale. The larger portion of the area has no outcrops, and the sequence of the beds can not be fully determined.

"At its base is a black to dark-gray shale and a very impure limestone that weathers to a buff earthy sandstone; these beds make a low ridge that is more or less continuous along the north border of the formation. They form the conspicuous hill at Conewago Chapel and here contain a thin bed of quartzitic sandstone. They also make the low hill east of Centennial and another 1 mile northeast of Edgegrove, where they pass out of the Gettysburg quadrangle.

"The limestone that overlies the shale is poorly exposed in most places, but west of Brushtown hard blue dolomite and coarse white to pink marble are exposed and considerable hard white chert and siliceous limestone are found in the soil locally.

"The next traceable bed is a light-gray even-grained sandy limestone that weathers to coarse porous buff sandstone which is dug for building sand at several places. It is interbedded with impure blue limestone and some black shale. It makes a more or less continuous band across the area, ... but is most conspicuous on a low ridge between McSherrystown and Midway and another west of Brushtown, where it is dug for sand.

"The rest of the formation is chiefly compact, thin-bedded, very impure dark limestone, with some light banding, which rapidly weathers buff and at the surface soon passes into buff sandy clay soil. It has been quarried at several places, but even the quarry face in abandoned quarries disintegrates into soil after a short time, and few exposures can be seen. Around Lefevre the limestone contains glassy sand grains and contorted partings of shiny black shale and weathers to yellow soil containing many fragments of black shale and soft buff shale and quartz. Some of the sandy beds are fine limestone conglomerates with round grains of glassy quartz.

"The formation occupies all of the lowland south of the shale hills at Edgegrove and extends to the Harpers schist hills in the southeast corner of the area. Its thickness can not be ascertained, as the bedding is nearly everywhere obliterated and replaced by cleavage, but it is probably over 1,000 feet thick."

"South of an east-west line (3, p. 33) through Centennial and Edgegrove the limestone is not pure enough to be burned into high-grade lime, and the lime produced from quarries located there was used for local agricultural purposes. A large quarry in the northern part of McSherrystown formerly produced burned lime for agricultural purposes in two stone kilns but later produced chiefly crushed stone for roads and ballast, and rubble for foundations. The quarry is over 50 feet deep, about 300 feet across, and extends several hundred feet along the strike, in a southwesterly direction. The rock is largely a dark, slaty, fine-grained limestone with some beds of white crystalline limestone and limestone conglomerate, much of it veined with calcite. When visited in 1920 it was equipped with a Blake crusher, pan elevator, and screens, and supplied much of the ballast for the electric railroad to Littlestown. There are small quarries in the same kind of rock at many places to the southwest, particularly in the extreme southern part of the county near Littlestown, but most of them are abandoned or are operated only occasionally. One of these was operated by O. H. Parr in 1921, who burned some lime. W. V. Sneeringer has produced crushed stone at a quarry ½ mile northwest of Littlestown since 1920." The stone from the quarry was originally burned for agricultural lime. It is a thin-bedded, blue, slaty limestone in places containing much vein calcite. The dip and strike are variable in the quarry and there are two places where the strata are sharply folded. The average strike is about N89°E., dip 21°SE. Considerable rottenstone near the surface must be discarded as weathering develops a shaly product. The quarry is about 300 feet long, 125 feet wide and 75 feet deep. The stone is taken from the quarry by means of a bucket suspended from a cable 325 feet long that crosses the quarry. The capacity of the plant is about 100 tons. The coarse product and chips are used by the State Highway Department and the fine product is used in the manufacture of hollow concrete blocks.

Beekmantown (?) limestone.—"Limestones (4, p. 8) are exposed in the lowland east of South Mountain about Fairfield, where the cover of Triassic sandstones has been removed by erosion. The outcrops are so largely concealed by stream alluvium, mountain wash, and residual soil that the details of their character and relation can not be clearly determined nor their thickness measured. The limestone around Marshall is a rather pure blue limestone finely laminated with impurities, with some white to pink marble, and closely resembles the Beekmantown of the Cumberland Valley. It has been quarried and burned for lime at several places. Limestone locally exposed near Virginia Mills is earthy and weathers to buff shaly fragments and tripolite and thus resembles the Elbrook limestone of Cumberland Valley, but it is not separately mapped. The limestone is more than 3 miles wide at Fairfield and narrows gradually northward. South of Middle Creek the limestone is thinly covered by limestone conglomerate of Triassic age, and small areas of the Beekmantown (?) limestone may be locally uncovered in the area mapped as Triassic conglomerate.

"As fossils have not been found in the limestone about Fairfield, no positive correlation with the formation in the Cumberland Valley can at present be made.

"Lithologically most of it resembles the Beekmantown so closely that this name is tentatively applied to it. The fact that fossiliferous

Beekmantown limestone is present in the valley around Frederick, Md. about 25 miles to the southwest, similarly exposed at the western edge of the Triassic rocks, favors this correlation. It is possible that the earthy limestone around Virginia Mills may prove to be Conococheague or Elbrook and should be separated from the Beekmantown."

TRIASSIC LIMESTONE

"South of the Chambersburg pike (4, p. 10) small limestone pebbles appear in the conglomerate and upper beds of sandstone, but not in sufficient number to warrant calling the rock a limestone conglomerate. Three-fourths of a mile southwest of Orrtanna a conglomerate composed largely of limestone pebbles has been quarried for lime. Thence south to Virginia Mills and Fairfield the Paleozoic limestone is exposed and the limestone conglomerate, which probably once overlay it, has been removed by erosion. A narrow band of conglomerate appears on the west side of Sugarloaf, widens southward, and beyond Middle Creek underlies practically the whole lowland. Its outcrop narrows again to a slender band between McKee Knob and the foothills of Jacks Mountain, the narrowness being due in part to faulting.

"The pebbles of the conglomerate average 2 to 3 inches in diameter, many being as much as 5 inches. They are largely composed of lime and dark gray to pink, fine, saccharoidal marble, gray dolomite, and gray impure limestone. The pebbles are generally rounded, although some are subangular. The matrix is red to gray calcareous clay or fine sand, which cements the pebbles into a compact rock. The limestone conglomerate has been quarried and burned for field lime at many places in the area but in general is too thin for extensive quarrying. The thickest beds seen are exposed in quarries east of Fairfield, where at most 20 to 25 feet is present. Southward in Maryland, especially near Point of Rocks, the conglomerate is thick and compact and has been quarried on a large scale for ornamental stone. In the trade it goes by the names 'calico marble' and 'Potomac marble.'"

"The limestone (3, pp. 33-34) in the vicinity of Fairfield has been quarried and burned for agricultural lime for local use at a few places. A quarry 1 mile northeast of Fairfield was operated by S. S. McCleaf until 1915 for the production of lime. It is in Triassic limestone conglomerate. The elongated pit, now overgrown, was 15 feet deep and the limestone was burned in three shaft kilns. Many small depressions in the lowland in this vicinity mark places where limestone was formerly quarried for lime but rock is no longer exposed there. Some of these pits are in Triassic conglomerate but others are in the underlying Paleozoic limestone."

A quarry in the Triassic limestone was being operated in 1930 one mile west and slightly north of Fairfield by the Fairfield Lime & Stone Co. The quarry was opened in 1927. It is about 150 feet in diameter and 40 feet deep. Crushed stone is produced and also lime is burned in two kilns near the quarry. The capacity of the plant is about 100 tons of crushed stone per day. The stone is a coarse limestone conglomerate containing rounded to angular limestone pebbles varying in size up to 4 inches in diameter. In color they range from pink, red, white, gray, bluish gray, bluish black and brownish yellow, held together by a calcareous matrix gray to pinkish gray in color.

The matrix is less pure than the pebbles, as can readily be seen near the top where the latter have been partially or completely dissolved, leaving cavities; the cementing material remains although leached of its calcium carbonate and enriched by limonite. No bedding planes can be determined in the quarry. Many faults are observable but the amount of displacement can not be determined. The superintendent of the quarry thinks that the deposit is about 100 feet thick, which opinion is based on some drill holes in Fairfield. There is a large spring in one side of the quarry. When wet the stone is especially attractive and would make a handsome ornamental marble for interior rock. It seems to have economic possibilities for such a purpose although the deposits would have to be first thoroughly investigated.

Analyses of limestones of Adams County

	1	2	3	4	5	6	7	8
$CaCO_3$	69.02	76.05	85.90	75.63	65.92	89.55	73.59	60.77
$MgCO_3$	21.39	1.03	11.64	17.35	27.10	2.86	20.62	34.01
SiO_2	7.35	21.90	1.65	5.08	5.01	6.16	4.42	4.37
Al_2O_3	1.19	0.20	0.17	1.08	0.99	0.63	0.39	1.08
Fe_2O_3	0.90	0.66	0.53	0.76	0.83	0.66	0.82	0.74
S	0.012	tr.	tr.	tr.	0.00	0.014	0.00	0.00
P	0.014	0.009	tr.	0.008	0.023	0.009	0.004	0.12

	9	10	11	12a	12b	12c	12d
$CaCO_3$	54.68	52.58	69.93	67.95	75.82	98.19	51.70
$MgCO_3$	42.58	40.00	25.10	28.88	20.22	0.20	46.80
SiO_2	1.80	5.41	3.93	1.85	1.51	0.60	0.60
Al_2O_3	0.06	1.20	0.43	0.25	0.24	0.08	tr.
Fe_2O_3	0.79	0.70	0.53	0.79	0.62	0.77	0.66
S	0.013	0.00	tr.	0.052	-------	-------	-------
P	0.007	0.014	0.008	0.007	-------	-------	-------

1. Two old pits on farm of A. J. Bair, 3 miles southwest of McSherrytown. Average of 2 samples.
2. Old pit on farm of A. Grove, 2 miles southwest of McSherrystown.
3. Abandoned quarry on farm of Andrew Rudisville, 1 mile west of Bittinger.
4. Small pits on farm of John Krug, 1 mile west of Bittinger. Average of 5 analyses.
5. Small opening on farm of John Krug, 3 miles northwest of Hanover, ¾ mlie north of Bittinger. Average of 2 samples.
6. Abandoned Slagel quarry 2¾ miles northwest of Hanover.
7. Jacob Moul quarry, 2½ miles northwest of Hanover. Average of 6 samples.
8. Two abandoned quarries on farm of Clayton Berkheimer, 2½ miles northwest of Hanover. Average of 4 samples.
9. Outcrop on farm of J. H. Barnett, 2¼ miles northwest of Hanover.
10. Abandoned quarry of George Slagel, 2⅛ miles northwest of Hanover.
11. Steacy-Wilton quarry 2¼ miles northwest of Hanover. Average of 82 samples.
12. Bittinger quarry of Bethlehem Mines Corp., 2¼ miles northwest of Hanover. a. Average analysis of 136 samples; b. Average analysis of 15 samples; c. High calcium stone; d. High magnesium stone.

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As shown in the section which follows, limestones occur in Allegheny County at a number of different horizons. All are thin, variable in thickness and composition, and of little economic importance. Some of them are absent in many localities, thus showing their lenticular character. In earlier years many of them were quarried on a small scale to obtain stone for burning for agricultural lime. For this purpose they were fairly satisfactory but they are not suffciently valuable to justify their exploitation where much overburden must be moved.

Generalized geological section of Allegheny County

Permian
- Dunkard series
  - Washington group
    - *Colvin Run limestone*
    - Waynesburg "A" coal
    - *Mount Morris limestone*
    - Waynesburg sandstone
    - Cassville shale

Pennsylvanian
- Monongahela group
  - Waynesburg coal
  - Brownsville sandstone
  - Little Waynesburg coal
  - *Waynesburg limestone*
  - Uniontown sandstone
  - Uniontown coal
  - *Uniontown limestone*
  - *Benwood limestone*— { *Bulger* / *Dinsmore* }
  - Sewickley (Mapletown) coal
  - *Fishpot (Sewickley) limestone*
  - Redstone (Pomeroy) coal
  - *Redstone limestone*
  - Pittsburgh sandstone
  - Pittsburgh coal
- Conemaugh group
  - Lower Pittsburgh sandstone
  - Little Pittsburgh coal
  - *Upper and Lower Pittsburgh limestones*
  - Connellsville sandstone
  - Little Clarksburg coal
  - *Clarksburg limestone*
  - Morgantown sandstone
  - Wellersburg (Elk Lick) coal
  - *Wellersburg (Elk Lick, Barton) limestone*
  - Birmingham shale
  - Duquesne coal
  - *Duquesne limestone*
  - Grafton sandstone
  - *Ames limestone*
  - Harlem (Friendsville) coal
  - Pittsburgh red beds
  - Saltsburg sandstone
  - Bakerstown coal
  - *Woods Run (Cambridge) limestone*
  - Thomas (Wilgus, Bakerstown) coal
  - *Pine Creek limestone*
  - Buffalo sandstone
  - *Brush Creek limestone*
  - Brush Creek coal
  - Mahoning sandstone
  - Johnstown iron ore
  - Mahoning red beds and *limestone*
  - Piedmont coal
- Allegheny group
  - Upper Freeport coal
  - *Upper Freeport limestone*
  - Butler sandstone
  - Lower Freeport coal

Most of the descriptions which follow are largely taken from M. E. Johnson's report on the Geology and Mineral Resources of the Pittsburgh Quadrangle (Atlas of Pennsylvania, No. 27) inasmuch as he has made a careful study of the limestones in the section (southern) of Allegheny County embraced within that quadrangle. The descriptions of the individual limestones given there apply as well to the same beds in other parts of the county.

LIMESTONES OF THE ALLEGHENY GROUP

Upper Freeport limestone. The oldest limestone of Allegheny County exposed in outcrops is the Upper Freeport. It comes to the

surface only in a few stream valleys in the northern and northeastern portions of the county. Along Little Bull Creek in Fawn Township, the following section has been described.

Upper Freeport section in Fawn Township

	Ft.	*in.*
Limestone	2	0
Shale	1	3
Limestone	2	0
Shale		3
Limestone	1	5
	6	11

At this point it was at one time quarried and burned for lime. It is said to have yielded a very satisfactory product.

Along Big Bull Creek in West Deer Township, it is 2½ feet thick. In Shaler Township it is a compact, hard, ferruginous limestone about 4 feet thick and in Hampton Township it is 3 feet thick with the upper portion highly ferruginous.

LIMESTONES OF THE CONEMAUGH GROUP

Brush Creek limestone. The Brush Creek limestone is exposed in many places in the region lying to the north of the Allegheny and Ohio rivers. It is an impure sandy or shaly limestone, dark in color, highly fossiliferous and varying in thickness from 1 to 2 feet. There are no reports as to its ever having been quarried. It has been recognized in many places in Shaler, Hampton, Ross, Marshall, Ohio and Sewickley townships.

Pine Creek limestone. (17, pp. 69-70). "This marine limestone is stratigraphically the lowest which outcrops within the boundaries of the quadrangle (Pittsburgh). It is found where Youghiogheny River and Turtle Creek have cut deep into the Murrysville anticline, and near the north boundary of the quadrangle where Allegheny River and its tributaries have cut equally deep into the Amity anticline and the rapidly rising strata in Shaler township. In the latter district, north of Millvale, the limestone is first seen in the stream bed a quarter of a mile southeast of B. M. 804. Following this stream and Evergreen Road to the northwest, the limestone is again well exposed about a third of a mile northwest of B. M. 804, at a small quarry which at one time was operated in the Buffalo sandstone, immediately underlying the Pine Creek limestone. Where first seen in the stream bed, the limestone is 8 inches thick, gray, brittle, sparingly fossiliferous, contains small flakes of biotite, which give it a speckled appearance, and weathers to a reddish color. At the quarry little more than half a mile away it is 21 inches thick, hard and sandy, and merges into the massive sandstone below it. Only 200 yards or so to the west, and less than a fifth of a mile north of the quadrangle boundary, it is 6 inches thick and underlain by 15 feet of clay. A hundred yards farther and one finds only 2 inches of limestone, again underlain by clay.

"The limestone may be seen again in its typical sandy, sparingly fossiliferous aspect along the Baltimore & Ohio tracks at the north boundary of the quadrangle and within the borough limits of Etna.

At this point it is 18 inches thick and directly above massive Buffalo sandstone.

"The top of the limestone is exposed in the bed of the little stream which flows into Allegheny River at Nadine. Its appearance here is similar to its appearance southeast of B. M. 804, Shaler township, and to its appearance in the valley half-way between Sandy Creek Station and Verona. In the latter place it is gray, brittle, apparently quite pure and almost non-fossiliferous; in fact, pink crinoid plates were the only fossils that could be found.

"A very good exposure of the Pine Creek limestone occurs at Glenover on the west side of Allegheny River about half a mile north of the quadrangle boundary. There the limestone is hard and sandy and changes rapidly in thickness from a few inches to a maximum of 33 inches.

"The best locality for the collection of fossils is in the vicinity of Trafford City. There the limestone is fairly pure, fossils are abundant, and the outcrop of the limestone is quite extensive. Moreover in that vicinity fossils are fairly abundant in the shale above the limestone and can be dug from the shale in a good state of preservation. In the vicinity of Versailles the limestone is again very hard and massive and the fossils are generally broken. In this locality also one may view the rapid change in the strata below the Pine Creek limestone. On the north side of Dead Man's Hollow, which is west and across the river from Versailles, the limestone is underlain by 2½ feet of sandy shale and then sandstone. On the south side of the same hollow the limestone merges directly into the sandstone. Half a mile north, at the mouth of Snake Hollow, it is underlain by at least 8 feet of clay, the base of the bed being concealed.

"The appearance of the limestone in its different outcrops has been rather fully described because of the importance of this bed as a "key" rock in mapping structure, and because in the past it has frequently been confused with the Brush Creek limestone which occurs 65 to 95 feet below it and which does not outcrop within the limits of this quadrangle.

"Certain types of fossils, particularly *productus* and *spirifers*, are rather common in the Pine Creek limestone and stand out prominently on weathered surfaces. These fossils also serve to distinguish the Pine Creek from the Ames and Brush Creek limestones.

"The Pine Creek limestone occurs from 45 to 55 feet below the upper Woods Run limestone, and from 127 to 178 feet below the Ames. In general the intervals are progressively less from east to west; the one radical exception being that in the vicinity of Terrace, Mifflin Township, the interval from Ames to Pine Creek is greater than anywhere else near by. The decrease in interval from there towards Hays is very rapid."

North of the Pittsburgh quadrangle, in the northern part of the county, the Pine Creek limestone has been described in East Deer Township where it is little more than an impure iron ore; in the bed of Little Deer Creek in Indiana Township, where it is 1½ feet thick; in Hampton Township with a 2-foot thickness; in Ross Township, where it is only 6 inches thick; in Marshall Township; and in Ohio Township where it is a light dove-colored, brecciated, fossiliferous bed about 2 feet thick.

Woods Run limestone. Johnson gives the following descriptions of this limestone. (17 pp. 66-69).

"The Woods Run limestone is an impure, fossiliferous limestone occurring in one or two thin beds from 80 to 119 feet below the Ames and from 35 to 55 feet above the Pine Creek limestone. A thin coal, never more than 6 inches thick, frequently occurs just below the upper bed or at the horizon of the upper bed in places where that bed is missing. Many types of fossils were found in the Woods Run limestone and although at present no index fossils can be listed to identify this horizon, it can be said that in general there is a much greater proportion of gastropods than in either the Ames or Pine Creek limestones.

"The Woods Run horizon is well exposed at Nadine, where the upper limestone bed, 5 to 6 inches thick, is 102 feet below the Ames and 17.4 feet above the lower limestone bed which is 2 to 4 inches thick. The Woods Run coal does not occur in this vicinity. Recently a cut made near the junction of the old Squaw Run brick road and the new concrete road which follows up the valley, exposed two inches of ferruginous, argillaceous, Woods Run limestone at an elevation of 787 feet. The Ames outcrops farther up the brick road at an elevation of 884; the interval between the two therefore is 97 feet. Neither the coal nor the limestone beds occur in the northwest part of the quadrangle. At the mouth of Ninemile Run, 2 inches of Woods Run coal occurs about 83 feet below the Ames. Following up the stream the coal disappears but in its place one finds 0 to 3 inches of typical Woods Run limestone. Here the interval to the Ames appears to be about 90 feet. A third of a mile south of the station at Trafford City the Woods Run horizon is well exposed along the Pennsylvania Railroad tracks, the section being as follows:

Section a third of a mile south of Trafford City

	Ft.	*in.*
Shale, gray towards base, greenish-yellow above,	40	
Lime, fossiliferous, Woods Run		2
Clay, many limestone nodules	3	
Shale, yellow or reddish	5	
Limestone, fossiliferous (?), Woods Run		1½
Clay, greenish-yellow	5	
Sandstone, Saltsburg.		

"A very complete section of the Conemaugh from the Ames limestone to the Buffalo sandstone is exposed in the quarry of the Union Sewer Pipe Company, across the river from Versailles.

Section at Union Sewer Company's quarry

	Ft.	*in.*
Limestone, fossiliferous, Ames		
Clay and clay-shale, red	18	
Shale, greenish-yellow	16	
Clay, gray, but weathers red	4	8
Shale, gray at base, greenish-yellow towards top	48	
Limestone, fossiliferous, impure, Woods Run		2½
Coal		2 to 4

Clay, gray	5	5
Shale, greenish-yellow, weathers red	4	
Limestone, impure, Woods Run (?)		2½
Clay, olive-drab, weathers red	3	2
Shale, greenish-gray	32	5
Limestone, sandy fossiliferous Pine Creek		7 to 15
Buffalo sandstone	25+	

"A careful search for fossils in the lower limestone bed was made both here and near Trafford City, but none were discovered. The exceedingly impure character of the limestone doubtless accounts for this. In the valley of Long Run between Youghiogheny River and B. M. 815 and also in Snake Hollow, the next valley to the north, both the Woods Run limestone and coal are exposed at a number of places and they proved very useful in determining the structure of the rocks in that locality. The interval from the Ames to the upper Woods Run limestone or coal at Versailles ranges from 90 to 100 feet; at Trafford City the interval is 95 feet."

Ames limestone. Johnson gives the following descriptions of the Ames limestone in the Pittsburgh Quadrangle (17 pp. 62-64).

"This marine limestone is the highest, stratigraphically, of all the marine limestones occurring in western Pennsylvania. Because of its position almost in the middle of the Conemaugh, its widespread occurrence and easy recognition, it is a most valuable aid to the geologist and from that standpoint ranks next in importance to the Pittsburgh coal in the vicinity of Pittsburgh. In its typical occurrence it is a greenish-gray or greenish-yellow limestone from 6 inches to 4 feet thick. Where it is 2 to 4 feet thick it usually occurs as two or three closely spaced beds separated one from another by a few inches of limy shale. It is always marked by an abundance of fossils, chief among which are crinoid stems, *Chonetes granulifer* (a small brachiopod) and *Ambocoelia planoconvexa* (small, marine bivalve with a prominent beak). Occasionally it is shaly and soft, as in places between Troy Hill southwest of Herrs Island, and Millvale; ordinarily it is more resistant to weathering than the adjacent soft shale and clay, and stands out prominently except where covered by vegetation. It was found everywhere the horizon outcrops except on one side of the little knoll at B. M. 740, mouth of Peters Creek (n.b. the knoll is not shown on the topographic map), at which point it was eroded previous to the deposition of the Grafton sandstone."

In the northern part of the county it is developed as one of the most persistent beds. Along Little Deer Creek in Indiana Township, it is a greenish rough-looking fossiliferous rock composed of a 1-foot bed of fairly good limestone at the top, a bed of candy limestone at the base, the two layers separated by 4 inches of shale. It was quarried and burned here but yielded poor lime.

It is present in Shaler Township; in Hampton Township where it is 2½ feet thick; in Reserve and McClure townships with a thickness of 2 to 3 feet; in Ross Township it is 2 feet thick; 4 feet thick in McCandless Township; is present in Pine Township; is only 1 foot 6 inches thick in Franklin Township in one place where it was once quarried and burned; is 2 feet thick in Ohio Township and 3 feet thick in Sewickley Township.

The following descriptions also are quoted from Johnson (17).

Duquesne limestone. "The Duquesne limestone is a thin fresh-water limestone which occasionally appears directly below or within a few feet of the base of the Duquesne coal. It is most conspicuous in that part of the bluff on the north side of Allegheny River which faces Herrs Island, the limestone attaining its greatest thickness, 3½ feet, at a point directly opposite the north end of the island. A hundred yards from the mouth of Becks Run large blocks of Duquesne limestone, 8 to 12 inches thick and containing great quantities of ostracod shells, were noted. A third interesting occurrence is along the Peters Creek branch of the Pennsylvania Railroad, about 600 yards southwest of B. M. 740 on the bridge over Peters Creek. At this point the Grafton sandstone is unusually thick and the strata above the limestone are concealed, hence the correlation of the limestone, here 15 inches thick, was in some doubt until the section near B. M. 740 was studied."

Wellersburg limestone. "The Wellersburg limestone is seldom seen. Where it does occur it is impure and usually nodular, and is found in the middle or towards the base of the Wellersburg clay."

Clarksburg limestone. "The greatest thickness of the limestone occurs near Coulter in the south tip of Versailles Township. The following section was noted in the river bluff above the railroad tracks about half-way between Coulter and Robbins Station.

Section of Clarksburg limestone southeast of Coulter

	Ft.	*in.*
Concealed		
Limestone		10
Shale and thin sandstone beds	5	
Limestone, massive	4	
Shale, sandy	1	
Sandstone, Morgantown		

"Across the river from Coulter the rapidly changing appearance of this horizon may be observed, the massive limestone bed noted in the section given above thinning rapidly from its greatest thickness here, three feet, until it is entirely replaced by strikingly cross-bedded sandstone. Another good exposure of the Clarksburg limestone occurs in the valley south of Boston and leading to the Wiley Run road. Here also there are two beds of limestone and at a point about one mile south of B. M. 780 they measure 30 inches (upper bed) and 36 inches (lower bed). This is the maximum observed thickness of the Clarksburg limestone. In other parts of the quadrangle the limestone seldom attains a thickness of more than one foot and is frequently entirely lacking from the section.

"The Clarksburg limestone and associated clay beds occur from 90 to 135 feet below the base of the Pittsburgh coal, the average interval to the limestone being about 105 feet."

Pittsburgh limestones. "As many as eight different beds of limestone have been noted within 70 feet below the base of the Pittsburgh coal. In some places only one or two limestone beds occur in that interval. Most of the beds are irregular and local in their occurrence

and because of that fact it has been deemed wisest to classify them all under the name Pittsburgh limestone, rather than attempt to attach individual names to each. The beds in this 70 foot interval are so thin and diversified that it was not possible to show the character of this part of the Conemaugh in the illustrations. For that reason a few typical sections are given in detail."

Section ½ mile south and a little west of Youghiogheny and Monongahela Rivers.

	Ft.	in.
Pittsburgh coal		
Shale, thin sandy lenses		10
Shale, carbonaceous		10
Limestone		0-7
Clay, gray to greenish	5	
Coal, shaly		4
Limestone, impure, dark gray	1	
Clay containing limestone nodules	3	
Shale	3	
Sandstone		3
Shale	1	
Clay	1	
Limestone		8
Clay	1	
Limestone	1	3
Clay	1	6
Shale, sandy	7	
Clay	5	
Sandstone		

"Section ¼ mile northeast of B. M. 999, east of Wilkinsburg

	Ft.	in.
Pittsburgh coal		
Fireclay	1	
Shale, sandy		5
Limestone	1	3
Clay		5
Sandstone, shaly	9	
Shale, carbonaceous		6
Limestone, massive, (3 beds)	4	1
Clay		2
Shale, carbonaceous		3
Clay		3
Shale, bituminous		4
Limestone		8
Clay	1	
Limestone, nodular	1	6
Clay, limestone nodules	3	
Shale, sandstone	7	
Limestone	1	4
Clay		3
Limestone		8
Clay, limestone nodules	2+	

"The thickest and most persistent of the Pittsburgh limestones occurs from 25 to 40 feet below the base of the Pittsburgh coal. It attains its maximum development in the southern third of the quadrangle."

LIMESTONES OF THE MONONGAHELA GROUP

Fishpot limestone. "The Fishpot limestone in this region is thin and irregular in its occurrence. As a sweeping generalization, it may be said that it is frequently present in the southern half of the quadrangle and usually lacking in the northern half. Where present it occurs a few feet below the Sewickley coal horizon and averages about four feet in thickness. The following section illustrates the character of this part of the Monongahela group.

Section ¼ mile north of Cowansburg, Sewickley Township

	Ft.	in.
Limestone, Benwood		
Clay, ferruginous	3	
Coal, Sewickley		7
Clay-shale, gray	3	
Shale, some thin sandstone beds	5	
Shale	12	
Shale, bituminous	1	
Clay, limestone nodules	2	
Limestone, gray, Fishpot	2	
Clay-shale	1	
Sandstone, hard, gray, calcareous	3	
Shale, gray	11	
Clay, yellow, limestone concretions	3	6
Shale, sandy, and thin sandstone beds	4	
Shale, drab	4	
Sandstone, hard gray, flaggy, or Sewickley	16	
Concealed	4	
Sandstone, hard, gray, calcareous Sewickley	3	
Shale and concealed	10"	

Benwood limestone. Above the Sewickley coal is a series of strata, aggregating in places 160 feet, which was formerly called the "Great limestone;" later, in accordance with the system of using geographic terms to designate geologic divisions, it was named the Benwood limestone, from the town of Benwood, W. Va., a short distance below Wheeling. The name Benwood was later restricted to the lower limestones of this interval and the name Uniontown, already in the literature, was retained for the upper limestones. It is in the restricted sense that Benwood is here used. Between the Benwood and Uniontown limestone members is a shale interval of 15 to 20 feet.

In the Burgettstown and Carnegie quadrangles the Benwood member consists of several beds of limestone separated by thick layers of shale. To two of these limestone beds, which are valuable oil horizon markers, Griswold[8] has given geographic names. The lower bed, of cream-white limestone, which lies 35 feet above the Sewickley coal, he has called Dinsmore, from exposures at Dinsmore, Washington County, Pa. The upper brown limestone bed he has called Bulger, from typical exposures at Bulger, Washington County. The Dinsmore limestone bed has a thickness of 4 feet and the Bulger limestone bed a thickness of 1 to 2 feet. These two limestone beds are separated by about 20 feet of shale, olive green at the top and reddish or yellowish below.

Uniontown limestone. Above the Benwood, separated therefrom by 15 to 20 feet of coarse calcareous shale, lies the Uniontown limestone

member, generally four separate beds, though none of them are well developed in the Burgettstown and Carnegie quadrangles. The first consists of about a foot of solid limestone, which shows a yellow surface when weathered and is blue when freshly broken; the weathered surface always shows small protuberances, due to the presence of particles that are more resistant than the surrounding matrix, which give it the appearance of being covered with small pimples and make it easily recognizable. Ten feet above this limestone is another, about a foot thick; it is composed of two slightly different materials, which on weathering produce a characteristic spotted surface which serves to identify the rock wherever found. From 16 to 18 feet above the last-mentioned bed is a blue limestone, which on weathering has a white residue of clay upon its surface but is nevertheless easily distinguishable from other white limestone because the blue generally shows through the surface color. A foot or so above this bed is the top stratum of the Uniontown limestone member. On weathered outcrops this is a soft yellow limestone, but on fresh fracture it shows brownish red. It disintegrates readily and is seldom found in a solid ledge, its outcrop usually being marked by the presence of brown limestone nodules.

The only fossils in the Uniontown limestone are fish remains and minute ostracods.

Waynesburg limestone. "The following sections illustrate the character of the upper part of the Monongahela group (17, pp 37-38):

"Section 2¼ miles west-southwest of Frank

	Ft.	in.
Coal, Waynesburg	1	2
Shale, sandy	15	
Sandstone	5	
Shale, brown, sandy	20	
Limestone, dark grayish-blue	1	6
Shale, brown, sandy	7	
Sandstone, brown, cross-bedded	10	
Limestone, dark blue	1	

"Section 100 yards southeast of B. M. 1224, northwest of Willock

	Ft.	in.
Coal, Waynesburg	1	3
Clay		3
Limestone		2
Shale	13	
Sandstone, soft, thin-bedded	5	
Concealed	3	
Coal bloom, thin		2±

"Section 1¼ miles west-northwest of Bruceton

	Ft.	in.
Coal, Waynesburg	1	3
Shale with occasional thin sandstone bed	15	
Coal, Little Waynesburg		2
Clay		4
Sandstone and sandy shale	5	
Concealed	10	
Limestone, shaly		2

"In a number of localities where the Waynesburg coal had been eroded the Waynesburg limestone was found fairly well developed, particularly in Baldwin Township. A maximum of 14 feet of cream-colored, shaly limestone was observed in the railroad cut 1½ miles west and little south of Willock."

LIMESTONES OF THE WASHINGTON GROUP

The Mount Morris and Colvin Run limestones are probably present in the highest hills in the southern part of the county, but they have not definitely been recognized. They are better developed in Washington and Westmoreland counties. They are of little importance.

CALCAREOUS MARL

J. B. R. Dickey, describes a calcareous marl deposit in Allegheny County in Mim. Bulletin 76 of this Survey as follows (18, p. 10):

"A deposit of fine textured, white marl analyzing over 90 per cent carbonate occurs on the farm of Stephen Bedner about 1 mile from Bridgeville. The deposit has not been inspected by the writer."

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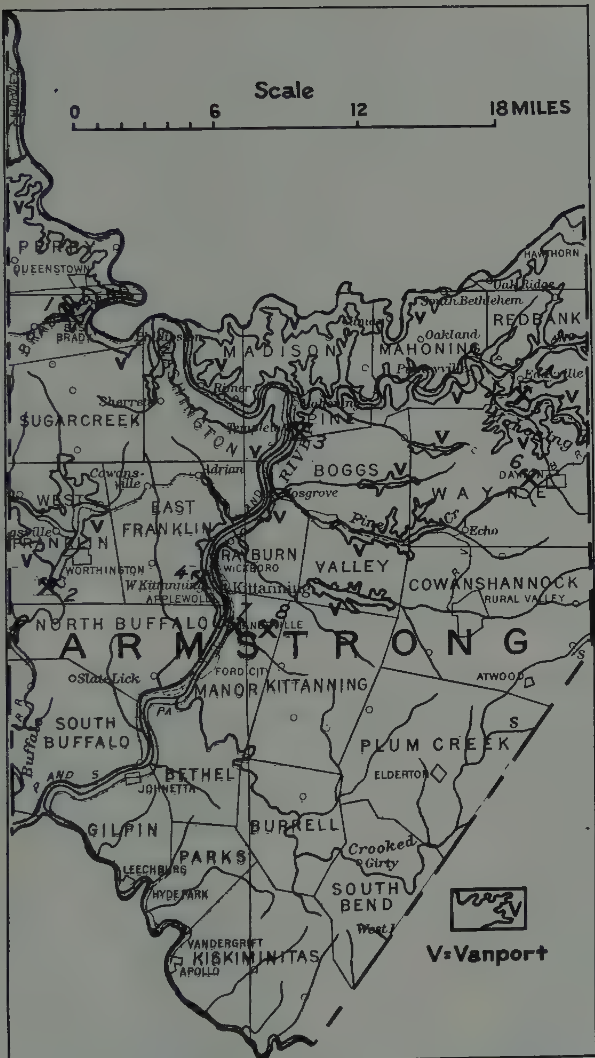

Fig. 2. Limestone areas in Armstrong County.

1. Pittsburgh Limestone Co., Kaylor
2. Pittsburgh Limestone Co., Worthington
3. Templeton Limestone Co.
4. Kittanning Limestone Co.
5. J. W. Best
6. D. D. Marshall
7. Ford City Lime and Coal Co.
8. S. M. Hershberger & Son

ARMSTRONG COUNTY

The limestones of Armstrong County are of major importance and have been quarried and mined extensively at several different places. For several years four large operations have been located near Kaylor, Worthington, Templeton, and Kittanning, with many small projects. With better railroad facilities and increased demand other quarries or mines could be opened. In no other counties in the State has limestone mining been carried on so successfully and on such a large scale as in Armstrong and the neighboring county of Butler.

In the geologic section that follows, compiled from various sources, are given the various members that have received names. These include practically all the coal and limestones but not many of the shales and sandstones that comprise the major portion of the stratigraphic column.

Although a number of limestones are given in the section and are described in the following pages, only two are of any particular importance—the Vanport and Upper Freeport. The Vanport is especially valuable as it is well adapted for use as flux, lime, cement, pulverized limestone (raw), and for the construction of hard-surfaced roads. It will become of increasing importance as transportation facilities are improved. The Upper Freeport limestone is mainly valuable for use as a fertilizer, either raw or burned to lime, and as such has long been used. The other limestones, although utilized in a few places, are of little consequence.

Generalized geologic section of Armstrong County

	Feet
PENNSYLVANIA SYSTEM	
Monongahela group	200
Benwood limestone	
Sewickley coal	
Sewickley (Fishpot) limestone	
Redstone coal	
Pittsburgh sandstone	
Pittsburgh coal	
Conemaugh group	650
Pittsburgh limestone	
Connellsville sandstone	
Morgantown sandstone	
Ames limestone	
Bakerstown coal	
Brush Creek coal	
Brush Creek limestone	
Saltsburg sandstone	
Mahoning sandstone	
Allegheny group	360
Upper Freeport coal	
Upper Freeport limestone	
Upper Freeport sandstone	
Lower Freeport coal	
Lower Freeport limestone	
Lower Freeport sandstone	
Upper Kittanning coal	
Johnstown limestone	
Middle Kittanning coal	
Lower Kittanning coal	
Kittanning sandstone	
Vanport (Ferriferous) limestone	
Clarion coal	
Clarion sandstone	
Craigsville coal	
Brookville coal	
Brookville fire clay	
Pottsville series	140
Homewood sandstone	
Mercer coals and shales	
Mercer limestone	
Connoquenessing sandstone	
MISSISSIPPIAN SYSTEM	
Pocono series	345
Burgoon (Mountain or Big Injun) sandstone	
Cuyahoga (Meadville) shales	

Distribution of the Geological Formations. The oldest strata exposed belong to the Pocono series. These are sandstones and shales and can be seen along Allegheny River between Phillipston and Templeton. Some of the earlier workers believed that the Mauch

Chunk series was also present in the region but it is now believed to be absent due to an erosional unconformity. The Pottsville strata composed mainly of sandstones but with some shales and a single bed of impure limestone are exposed in the major stream valleys of Armstrong County as far south as Mahoning Creek, with a small outlier along the South Fork of Pine Creek in the vicinity of Oscar. The Allegheny group forms the upper valley slopes in the northern part and the valley bottoms in the southern part of Armstrong County. The Conemaugh constitutes the major portion of the uplands. The Monongahela group has a very limited development in the uplands in the southeastern part of Armstrong County bordering Indiana County.

The strata of Armstrong County have been slightly folded in broad anticlines and synclines but have not been seriously disturbed. Over wide areas the beds are approximately horizontal and in no place observed are the dips steep. Dips of more than 5° are unusual. Apart from the gentle folds there is a general dip to the southwest so that in general one encounters younger strata in the southern part of the county and older beds in the northern part.

Few, if any, of the different strata recognized are continuous throughout the entire county. This applies particularly to the limestones.

The geologic column above contains the names of 9 limestones. Of these the Vanport overshadows all others in importance; the Upper Freeport is of considerable value in several sections in the southern part of the county; the others are of little or no economic value.

LIMESTONES OF THE POTTSVILLE SERIES

Mercer limestone. The lowest limestone member in Armstrong County is the Mercer and it has been reported to outcrop in only one place, near McCrea Furnace, where it consists of 6 to 10 feet of sandy limestone lying about 140 feet below the Vanport limestone. It is of no value.

LIMESTONES OF THE ALLEGHENY GROUP

Vanport limestone. The Vanport limestone is a gray rock containing many marine fossils. In many places it is distinctly separable into two members, the upper gnarly or shaly and fairly impure, with the lower massively bedded, hard and pure. The lower member is generally two or three times as thick as the upper. The lower portion seldom contains less than 95 per cent calcium carbonate. The impurities are almost equally divided between magnesium carbonate, silica, iron oxide, and aluminum oxide. It is an excellent stone for flux and has been quarried and mined extensively for this purpose for local use and even for the Pittsburgh region in those places, where the stone is accessible for railroad transportation. As it generally outcrops along steepsided valleys it is seldom possible to obtain large quantities by open quarry methods and consequently underground mining has been necessary.

The stone is also well adapted for the manufacture of Portland cement although at present there is no cement plant in the county. A large quantity of the fine sizes produced in preparation of fluxing stone at Kaylor and Buffalo Creek is shipped to the Portland cement

plant of the Universal Atlas Company near Pittsburgh. Locally the Vanport is quarried by the farmers to be burned for agricultural lime or to be pulverized and used in the raw state. The better layers meet the specifications of the Highway Department and the stone is increasingly utilized for the construction of roads.

The Vanport varies in thickness considerably. For miles it may be regular and then suddenly decrease or entirely disappear within a very short distance. This change has been attributed to original differences in deposition, to subsequent removal before the overlying beds were deposited, or to underground solution at a later period. The prevalent view seems to be the first but probably the other explanations are also correct for some localities. One example to be described on a later page was noted where a part of the Vanport limestone was removed by the stream erosion before the deposition of the overlying shale.

The Vanport limestone is generally a grayish rock. It is of marine origin, as in places it contains abundant brachiopods and joints of crinoid stems and occasionally cyathophylloid corals, as well as pelecypods and gastropods. In thickness it varies from 0 to 20 feet, the latter thickness being reached at West Winfield, just across the line in Butler County, where it is extensively mined by the West Penn Cement Company for the manufacture of Portland cement (this report p. 261). The average thickness for the county, where exposed, is probably 10 to 12 feet, though in many well records it is noted to be about 20 feet thick. It generally has at least two massive layers at the base and thinner overlying beds separated by shale partings.

The limestone is notable from the fact that it bears upon its upper surface an iron ore that is generally a hard, often siliceous layer of impure hematite, limonite or siderite, ranging from a few inches to a foot or more in thickness. This was called "buhrstone ore" by the geologists of the Second Geological Survey of Pennsylvania because it is often underlain by cherty material in nodules or in thin bands. Sometimes the ore occurs as carbonate nodules in the first few feet of shales overlying the limestone. At Kittanning the ore is fossiliferous, containing abundant impressions of shells, mainly brachiopods, and furnishes proof of the ore being simply a replacement of the upper portion of the limestone by iron minerals carried in solution by circulating waters. The same condition exists elsewhere. Ruins of old blast furnaces can still be seen in several places in the county where this ore was smelted. The openings where ore was mined have been closed by collapsing roofs and are scarcely recognizable.

The limestone rises above the water in Allegheny River just below Kittanning and remains above water level up the Allegheny to the northern margin of the county.

The Vanport has not been found on the west side of the river nearly opposite Ewing. For an area about 1 to 2 miles on either side of Mosgrove it seems to be absent from both sides of the river. It has not been found over a considerable area on the north side of Allegheny River east of Rimer, nor in the hills along the south side for 4 to 5 miles above Gray's Eddy. It is absent also on the north side of the river just west of Phillipston. At other places the limestone seems to be present, although in certain localities very much thinner than usual. This is the case on the south side of the river

opposite Phillipston and at other points. Furthermore, the iron ore layer may be present although the limestone is wanting, as along the highway northwest of Phillipston where hematite ore occurs at the base of a heavy sandstone. Similar conditions prevail opposite Ewing, where the limestone is reported wanting, but, from the number of old pits which occur at this point just beneath a heavy sandstone, it is evident that the ore is present and was mined extensively. The Vanport occurs along Redbank Creek from the mouth of the stream to its headwaters. It outcrops along the valley of Limestone Creek to above Adrian, on Sugar Creek nearly to Kaylor, and up Huling Run to the vicinity of Sherrett. On Buffalo Creek the limestone is above water level for a mile north of the junction with Rough Run. It rises above Buffalo Creek again about 2 miles below Buffalo Mills and is about 250 feet above water on the axis of the Kellersburg anticline in the vicinity of Craigsville. It then drops to water level on Little Buffalo Run about three-quarters of a mile west of Nichola and on Patterson Creek near Fosters Mills.

Its horizon is above water on the Cowanshannock from about 1 mile east of the western margin of Valley Township to the western boundary of Cowanshannock Township. It is known to be present from its western outcrop to a point about 1 mile east of Greendale, but it is not known east of that point and it is apparently cut out by a heavy sandstone which occurs at its horizon in this locality. On the South Fork of Pine Creek it is revealed on the crest and flanks of the Greendale anticline. It rises to view at Pine Furnace, reaches an elevation of 150 feet above the creek about 1 mile west of Oscar, and descends below water level again about half a mile west of Echo. It is not known to be present everywhere along this creek, but probably it is. It is above water for about 3 miles along North Fork of Pine Creek on the western flank of the Greendale anticline, where it shows its usual thickness. In Scrubgrass Creek it rises to the surface about half a mile east of Goheenville and remains above the stream for about 3 miles to the eastward.

At water level on Crooked Creek east of Girty and around the "Loop" 2 miles west of the hamlet, the Vanport limestone is exposed. It shows 8 to 10 feet of solid limestone; it is dark bluish gray on the freshly broken surface, but reveals a large number of white fossils (mostly crinoid stems) on the weathered surface. It is compact, rather coarse, and very brittle. The richly-fossiliferous, weathered surface is a distinguishing feature. The exposed edge often has a pitted appearance, due to irregular weathering along bedding planes. Above the limestone are 22 feet of sandstone and shales, the upper layers containing iron ore nodules. This horizon is overlain by 8 feet of fire clay, often of poor quality, which underlies the Lower Kittanning coal bed.

The largest stone operation in the county is located along Sugar Creek between Kaylor and Bradys Bend, in Bradys Bend Township where the Pittsburgh Limestone Company, a subsidiary of the United States Steel Corporation, has three extensive mines. The original operation was by open cut quarrying but now all the work is underground. Two of the mines are located on the north side of the creek and the other on the south side. A section exposed near No. 2 mine, south side of Sugar Creek is as follows:

Section south side of Sugar Creek

		Ft.	in.
	Shale		
	Iron ore		4 to 10
	Discontinuous chert layer		0 to 2
1.	Thin bedded gnarly limestone	1	1
2.	Grayish blue limestone weathering to a dove color containing large crinoid stems	1	6
	Shale		4
3.	Massive bluish gray limestone	6	0
	Stylolite parting		
4.	Bluish gray limestone	4	4

In the mines, the sections at different places vary considerably. The lower bed is commonly 6 feet thick. The practice is to leave the two upper limestones as a roof and also as much as 16 inches of stone at the base. The reason for leaving the lower stone is on account of a somewhat higher silica content. The thickness removed averages 11½ to 12 feet. The drill hole records show a thickening of the Vanport to the northwest up to 20 feet, a slight thinning to the south and a rapid thinning to the east.

In mining, the room and pillar method is used. The main haulage entries follow the outcrop of the limestone into the hill roughly at right angles to the valley. The rooms are 40 feet wide with 20-foot pillars. Falls of roof in old rooms are not unusual, but very little timber is required. In one of the mines the main entry is used as a highway by the workmen who drive their automobiles into the mine to a distance of half a mile. Some vertical shafts are sunk from the surface for ventilation.

The stone from the three mines is hauled to a common crushing plant located in the valley. The stone is crushed to the desired size for blast furnace use, and the finer sizes are sold for road purposes or shipped for Portland cement manufacture. This plant has a reported daily capacity of 5000 tons.

The second largest limestone operation in Armstrong County also belongs to the Pittsburgh Limestone Company. This mine is located on the west side of Buffalo Creek about 1½ miles southwest of Worthington. The Vanport limestone in this section is considerably thicker than at Kaylor. A typical section is as follows:

Section in Buffalo Creek quarry

		Ft.	In.
	Shale, dark blue to black		
1.	Gnarly limestone, either massive or divided into 4 to 6 layers by thin partings of black shale. Large crinoid stems abundant	1	6
	Thin shale parting		
2	Limestone similar to above	1	6
	Thin shale parting		
3.	Thin bedded limestone with different layers separated by very thin shale partings. This layer commonly called "shelly bed"	2	0
	Shale parting. Thickest shale parting in section, ranging from 0 to 2" or 3"		
4	Gray limestone, massive when fresh but breaking into thin rough surfaced layers on weathering. Has local thin shale partings. This is the principal bed of stone and is of best grade	8	9

5. Blue to black limestone with some fossils. Breaks into more or less rectangular blocks when shot	4	3
Bluish black shale		

In mining, the two upper layers of limestone are normally left for the roof. Occasionally they break loose and when large blocks fall the overlying shale also comes down in large masses as it has been extensively broken by small faults that show in the numerous slickensided surfaces. When a break in the roof starts, large timbers are put in the mine some distance back from the break in an effort to stop the progress of the roof falls. Ordinarily the roof remains firm without any timbering for years after the removal of the workable stone.

In mining the stone, main entries are driven with 40 feet rooms leading off, separated by 20-foot pillars. The main haulage entry follows in on the bed, which outcrops only a short distance above the level of the creek. The power house is located within the mine about 1 mile from the entry and workmen drive their automobiles in to this point.

Layers 4 and 5 are drilled and shot down first. Layer 3 is then drilled by stoper drills and shot. In this mine all the limestone is taken out down to the underlying shale as there is no good parting within the lower bed of limestone. In fact, in places the underlying shale is so firmly attached to the base of the lowest limestone layer that some of it breaks away when the limestone is shot.

The stone is loaded by electric shovels and hauled outside to the stone crusher. The gyratory crusher is set to break the rock to 8 inches. Ordinarily everything from ¾ to 8 inches in size goes to the iron furnaces in the Pittsburgh region for flux. However, when there is an active demand for crushed stone or stone for Portland cement manufacture more of the smaller sizes are separated. The capacity of this plant is given as 3000 tons of rock per day.

In one place in this mine an old stream channel was observed, now filled with sand, clay, shale, fragments of limestone and iron ore concretion. The channel has been cut almost to the base of the limestone. At the deepest part of the channel 14 feet of the limestone had been removed. There is little doubt but that this was eroded by a current before the laying down of the overlying shale and while the limestone was still in an unconsolidated condition.

The Templeton Limestone Company has been operating a limestone mine in the Vanport about one mile south of Templeton to obtain fluxing stone and crushed stone for highway construction

Generalized section at Templeton Limestone Co. quarry

	Ft.	*in.*
Shale		
Iron ore layer, thin		
Limestone	1	2
Shale parting		
Limestone	1	6
Shale parting		
Gnarly blue stone		2 to 8
Massive limestone with one prominent break 52 inches from base	7	8
Shale		

The beds are very uniform for the distance followed, about 1700 feet at the time visited. The strata have a few gentle rolls. Mining and loading are done by hand. The stone is crushed and screened according to the demand. An analysis of this stone, said to be a fair average, is given on a later page. The daily production capacity is said to be 700 tons.

Across Allegheny River at Kittanning, the Kittanning Limestone Company operates a mine. The stone removed is massive in character and averages 8½ feet in thickness. About 3 feet of overlying limestone is left as a roof and about 6 inches of stone at the bottom A fault zone which is not clearly understood cuts across the property. The daily capacity of the mine is given as 1200 tons. In 1929, at the time visited, about 80 per cent was being sold for fluxing stone and the balance for crushed stone. An analysis is given on a later page.

During the summer of 1919, the writer and A. H. Fretz collected much information concerning the materials in Armstrong County suitable for highway purposes. The following disconnected notes made in this investigation on different localities where the Vanport limestone might be readily quarried supplement some of the information given above.

On Sugar Creek and tributary streams the Vanport limestone is abundant. There is little need for more quarries here, however, on account of the large operations of the Pittsburgh Limestone Company.

Near the mouth of Snyders Run the iron ore layer lying above the Vanport was formerly worked. There should be from 10 to 15 feet of limestone at this point.

Along the west bank of Huling Run the Vanport outcrops on the farms of Robert Hayes, Henry Rickel, Jacob Kocher heirs, J. W. Foster and T. V. McKee heirs. The Vanport is typical with an iron carbonate top layer. It is 20 feet thick. On any of these properties it could be developed and on the McKee property it is immediately accessible to the highway, has only a moderate overburden, and could be opened for a long distance on a narrow bench with almost negligible overburden. The McKee quarry shows only 4 feet of limestone but numerous well records give 18 to 22 feet as the thickness.

On the farm of Michael Wolf, half a mile up hill from Rimer station, considerable Vanport limestone has been dug by the farmers of the vicinity. It was worked along the hillside at the outcrop for a distance of about one-quarter mile. The openings are now partly filled but it seems that the limestone is about 8 feet thick, massive, and of good quality. A large amount could be removed in open cut with comparatively small removal of overburden and a very great amount could be obtained by mining.

A quarry in the Vanport limestone on the property of George Hynman at Nichola was actively worked for several years by the Punxsutawney Iron Company for flux.

On the highway west of Craigsville, the Vanport limestone outcrops in the road as if placed there as broken stone by road supervisors. This outcrop should be possible of development on the farms of that region.

The limestone mines on the east side of the valley of Rough Run at West Winfield have their adits in Butler County, but the greatest part of the material mined comes from the Armstrong County side.

These mines are the property of the Pittsburgh Sand Company, the Pennsylvania Clay Products Company, and the Winfield Sand Company. The Vanport is typical, gray in color and 20 feet thick. It dips eastward from Rough Run to Buffalo Creek. It outcrops along Rough Run 20 to 80 feet above the water line and along Buffalo Creek about 10 feet above the water line along the west bank. It is at or below the water level along the east bank. The limestone is used as flux. The iron carbonate layer was smelted at a blast furnace here; the furnace has been dismantled many years.

On the property of James Jones at the confluence of Rough Run and Buffalo Creek, the Vanport limestone is exposed in the east bank of the stream, and its solution cavities look like muskrat holes. On the west bank the limestone on the Charles Ross property is not visible as an outcrop. It may be hidden under the Winfield Railroad embankment or it may not outcrop at all.

In the north part of Kittanning the Vanport is exposed. It is about 9 feet thick, of which 8 feet is massive and of good quality. In the past it had been quarried in several places for lime.

On the south side of Red Bank Creek there are probably a number of places where the Vanport could be quarried easily, especially along the valleys of the short tributary streams. Near Oak Ridge some stone has been quarried and also mined. It was 4¾ feet thick at one of these openings. Half a mile south of South Bethlehem, on the land of the Pine Run Coal Company, the Vanport has been quarried to a small extent for lime. The opening is about 50 feet above the road. It seems to be 5 to 6 feet thick. The overburden conceals the bed in part. To obtain much stone it would be necessary to remove 10 to 15 feet of overlying soil and shale. Another similar old opening on the edge of the borough of South Bethlehem is now inaccessible for examination. About one mile west of this locality, D. and C. E. George have quarried the Vanport along the hillside for a distance of about 600 feet to obtain stone for burning. The overlying shale has slumped down and concealed the limestone. To obtain more stone it would be necessary to remove about 12 feet of overburden. The bed is said to be 6 feet thick. Two miles southwest of South Bethlehem, the Vanport has been quarried. Beneath a thin cover of decomposed shale, about 10 feet thick as a maximum, there is a 1-foot layer of ferruginous limestone overlying 6 feet of good grade massive limestone. The upper portion of the limestone is well filled with crinoid stems. Several acres of limestone could be obtained here without excessive stripping. Similar occurrences of the Vanport can be found on the south side of Redbank Creek westward to its junction with Allegheny River.

As stated above, the Vanport limestone outcrops along both sides of Mahoning Creek throughout its entire course. The following occurrences are probably typical. The Pittsburgh & Shawmut Railroad has uncovered the Vanport limestone for a long distance in its side hill cuts from Putneyville to Nitro and east to Little Mudlick Creek. The thickness is 6 feet. The upper part is iron carbonate ore. The overburden is shale and thick soil. The total length of limestone exposed here will measure about 2 miles. A 10-foot bench of the limestone could be developed without the removal of excessive overburden.

The Potter Coal Company has a small quarry in the Vanport limestone at the confluence of Little Mudlick and Mahoning creeks. The stone is used for burning. Adjoining the Potter Coal Company's quarry is that of Brown and McCullogh of Kittanning. These two properties could be developed without removing a large quantity of the shale overburden. The limestone is typical and 6 feet thick. About a mile and a half up Little Mudlick Creek, Joseph Beam has quarried the Vanport limestone which outcrops close to the creek line. Prospecting trenches were dug in the spring of 1919, uncovering the Vanport. This property would give a fair quantity of stone without excessive overburden. The thickness seems to be 6 to 7 feet.

John and Dal Hoffman have Vanport limestone on their property at McCrea Furnace. It is exposed in a steep bluff cut by Mahoning Creek. As the bank is very steep and the Vanport outcrops part way to the top, mining methods only could be used to get a large quantity of material. The formation has a thickness of about 8 to 9 feet.

J. W. Best has a large quarry on his property 1½ miles southeast of Eddyville. The Vanport here is 7 feet thick. The stone is typical and of excellent quality and uniform along the present opening of about 800 feet. The overburden would not become excessive back 20 feet from the present face and the rock could be opened over a longer area than at present. Such overburden as would be removed could be dumped over the adjacent bank. This property could supply a large quantity of material. It is accessible to the highway.

J. J. Kammerdeinner has a quarry on the Vanport limestone along Scrubgrass Creek east of Goheenville. The outcrop is close to the water level. This property could furnish a considerable quantity of stone in a quarry opened along the outcrop. The highway rather than the overburden would limit the extent of the quarry in width. About 4 to 5 feet of the bed lies above the creek level. Probably the whole thickness of 8 feet could be quarried without especial trouble from normal water.

William Marlin has a quarry opened on the Vanport east of the Kammerdeinner property. The bed is 6 to 8 feet, massively bedded, with iron carbonate rock at top. Above is a shale 10 feet thick with iron concretions and medium heavy sandstone beds capping it. The quarry is entirely above high water. Overburden would become serious but a linear quarry along the outcrop might furnish considerable quantity of stone without excessive stripping.

At Slabtown on the North Fork of Pine Creek there are exposures of Vanport limestone on several properties. Here the Vanport outcrops along the hill. The character of the rock is typical. The outcrop can be traced on the properties of Louis and Jacob Baum, P. W. Zimmerman, J. M. Upperman, Mrs. Sarah Lockhart and Abraham Heffelfinger to the property of Robert Heffelfinger. Two quarries in the Vanport on the latter's farm are close to the water line, one on the north and one on the south side of Pine Creek Fork. The one on the south side exposed Vanport limestone, heavy bedded and typical in color and hardness, 10 feet thick, although a small part at the top is iron carbonate rather than limestone. The base of the limestone is about 5 feet above water level. The overburden is a thin soil and weathered shale mantle about 10 feet thick at the highway, tapering to nothing at the outcrop along the creek bank. The average

width from highway to creek is about 75 feet. The outcrop along the creek bank is continuously exposed for 1000 feet and probably more.

Along the South Fork of Pine Creek the Vanport outcrops on both sides of the stream from near Pine Furnace to near Echo. The quarry of D. D. Marshall on the farm of H. L. Lepold, Dayton, Pennsylvania, located at Pine Furnace, was actively worked in 1919 to furnish pulverized raw limestone for farm use and later for crushed stone. The overlying iron ore was removed years ago for use in the furnace. The section of the quarry is:

	Ft.	*in.*
Soil and shale	5-6	
Limestone	1	
Shaly limestone		6-8
Massive Vanport limestone	5	6

A very large amount of stone could be obtained here at little expense.

About one mile west of Oscar, the Vanport is about 150 feet above the creek but descends both east and west. In most places it is concealed by hillside talus although it has been quarried in a number of places. The Pine Furnace quarry is probably typical.

The Vanport limestone is well developed in the vicinity of Stone House and Greendale along Cowanshannock Creek. Although the bed is generally concealed by hillside talus, it seems that a rather large amount of stone could be readily obtained. Just above the school west of Stone House small quantities of limestone have been quarried at many different times. Near the mouth of Long Run, some Vanport limestone has been dug on two adjoining farms. It is said to be 8 feet thick.

The Vanport limestone appears above the surface along Kiskiminetas River for about 2 miles above and 1 mile below the mouth of Roaring Run. Platt described it (2, p. 17) as being 10 feet thick, "of a dark grayish-blue color, compact, very hard and brittle, fine-grained, presenting a rough surface at the fresh fracture, and abounding in encrinitic stems. Its weathered face, dark and rough, is easily distinguishable at a glance from the Freeport Upper limestone, which has a smooth surface and is of a light blue color". Its outcrop occurs in the steep bluffs of the river, making it difficult to quarry. So far as known it has not been quarried at this point.

Analyses of Vanport limestone

	1	2	3
SiO_2	1.20	1.40	2.60
Al_2O_3	.42	.37	1.80
Fe_2O_3	1.14	1.43	1.05
$CaCO_3$	93.41	94.17	94.51
$MgCO_3$	2.01	1.36	
S.	.048		.028
P.	.044	.012	.076
Loss	1.03		

	4	5	6	7	8	9
$CaCO_3$	96.007	94.721	95.567	94.185	93.292	93.246
$MgCO_3$	1.498	1.044	1.422	1.483	.968	1.740
$Al_2O_3+Fe_2O_3$.	1.462	1.383	.930	2.089	1.713	1.667
SiO_2	.790	2.300	2.110	2.100	3.220	3.420
P.	.034	.047	.035	.031	.047	.032

1. Kittanning Limestone Company, west side of Allegheny River, opposite Kittanning. Analysis by Pittsburgh Testing Laboratory, October 22, 1927.

2. Templeton Limestone Company, 1 mile south of Templeton. Analysis furnished by company.

3. Vanport limestone quarried near Mahoning for flux. Analysis furnished by iron company.

4. Vanport limestone. Stewardson furnace limestone, Armstrong County, one mile east of mouth of Mahoning Creek, in Madison Township. F. B. and L. Laughlin, Fine-grained; full of fossil casts; pearl gray; with conchoidal fracture. (3, pp. 85-86).

5. Vanport limestone. J. A. Colwell's quarry, Armstrong County. One fourth mile northwest from Mahoning furnace. Rather compact and fine-grained; full of fossil casts, bluish gray; with conchoidal fracture. (3, p. 85-86).

6. Vanport limestone. Ross Reynolds' limestone, Armstrong County, ½ mile north from Kittanning. Fine-grained, fossiliferous; mottled with calcite; rather tough; light pearl gray. (3, pp. 85-86)

7. Vanport limestone. P. George, 2 miles west from South Bend, Armstrong County. Fine-grained; fossiliferous; mottled with calcite; dark gray. (3, p. 86)

8. Vanport limestone. P. Graff, near Buffalo Mills, Armstrong County. Fine grained; brittle; more or less stained with ferric oxide; fracture rough somewhat conchoidal; color, dark gray. (3, p. 86)

9. Vanport limestone. J. C. Rhea, one mile west of Greendale, Armstrong County. Rather coarse grained fossiliferous; brittle; bluish gray. (3, p. 86)

Johnstown limestone. In the recent work in Armstrong County by the geologists of the U. S. Geological Survey, the Johnstown limestone was not differentiated. Platt, however, in Report H5 of the Second Geological Survey (2) refers to it as present in a number of different places throughout the county. He records it with thickness of 1 to 4 feet. It is everywhere decidedly impure and practically worthless. Analyses of the bed from two different localities were made.

Analyses of Johnstown limestone

	1	2
$CaCO_3$	53.750	64.160
$MgCO_3$	9.989	1.838
Al_2O_3-Fe_2O_3	7.730	7.450
SiO_2	23.840	22.280
P	.131	.305

1. Johnstown cement. M Davis' limestone, Armstrong County, ½ mile southeast of Cochran's Mills. Outcrop specimen. Rather coarse grained; exceedingly hard and tough; bluish gray. (3, p. 85)

2. Johnstown cement. George S. Putney's limestone at Putneyville, Armstrong County. Rather coarse-grained; hard and tough; bluish gray; irregularly stained with carbonaceous matter. (3, p. 85)

Lower Freeport limestone. The Lower Freeport limestone seems to be missing in almost every part of Armstrong County. Seldom is limestone found at the horizon where this bed should occur. It has been described as present north of Garrett Run, where it is a ferruginous limestone about 2 feet thick.

Upper Freeport limestone. The Upper Freeport limestone is widespread throughout Armstrong County and has been quarried at many points to supply material for various purposes. Due to its wide extent and the almost complete absence of the Lower Freeport it is frequently designated as the Freeport limestone.

The Freeport limestone is best developed in Manor and North Buffalo townships. It is well exhibited along the bluff back of Manorville and Ford City where cut by the highways, along Garrett Run and its tributaries, along the run east of Ford City and in the ravines running down to the west side of Allegheny River opposite Ford City. In the ravine of Fort Run near Manorville, it is reported to be 28 feet thick and to contain several beds of rather distinctive character (Second Geological Survey of Pennsylvania, Report H5, p. 256). West of Allegheny River at Ford City it is 18 to 20 feet thick. These thicknesses are exceptional and attained only in this locality. On Garrett and Rupp runs and east of Ford City it ranges from 8 to 10 feet; westward from the river it becomes thinner and on Marrowbone Run and at Beatty's Mill is about 5 feet thick. On Buffalo Creek half a mile above Boggsville it is 2 feet thick. It could not be found on Sipes Run nor westward to the Butler County line. It occurs at the top of the knob half a mile northwest of Fosters Mills and is well developed i nthe hills in the neighborhood of Bradys Bend.

It is also present in the hills in the vicinity of Goheenville and southward and in the hills south of Putneyville. Along North Fork it occurs very generally as far east as Muff, where it just catches the higher hilltops. North of the South Fork of Pine Creek it occurs on the hills from Oscar to Dayton. It is quarried at points along the road south of Cowanshannock Creek in southern Rayburn Township and also on Hays Run.

In the southern part of the county the Upper Freeport is present along Crooked Creek and Taylor Run and for years was extensively quarried at Logansport and Kelly Station. It has been developed at many places along Kiskiminetas River, particularly in the vicinity of Apollo.

The Upper Freeport limestone is bluish to brownish gray in color and can be readily distinguished from the Vanport by the almost complete absence of fossils. Those that are present seem to be freshwater forms. It does not show the rough, gnarly surfaces so characteristic of the Vanport when broken but instead the broken surfaces present smooth, conchoidal surfaces. The Vanport commonly shows glistening spots of calcite cleavage faces, whereas the Upper Freeport limestone is uniformly dull in appearance. The pronounced conchoidal fracture and the ease with which it breaks when struck render it less desirable for highway use. In almost every exposure, as shown in sections given below, there are a number of different layers separated by thin shale bands.

In many places it has been quarried for lime burning and less commonly for crushed stone. It burns easily in open heaps but much has also been burned in stone kilns. When the small iron ore furnaces were in operation throughout the county, the Upper Freeport was quarried for flux and some was shipped. In recent years the Vanport limestone, which is superior in quality, has largely driven the Upper Freeport from the markets but locally it is still used.

The following detailed notes are mainly taken from a report by the writer and A. H. Fretz made for the State Highway Department in 1919, supplemented by some later work by the writer and in a few instances from a brief report by H. H. Hughes.

In the northern part of the county, west of Allegheny River, the Upper Freeport is of little value. In the vicinity of Sugar Creek, it outcrops in the higher portion of the bluffs. High up in the hills east of Sherrett, it has been quarried for lime in at least two places. Along Buffalo Creek the Upper Freeport is not continuous. It is present at the top of the knob half a mile northwest of Fosters Mills; it is 2 feet thick half a mile above Boggsville. It was not recognized on Sipes Run. Along Glade Run it is present as a fairly continuous bed and in several places it has been quarried to be burned for agricultural lime for local use. On the west side of Allegheny River, opposite Ford City, the Upper Freeport has been quarried for flux stone which was shipped to Pittsburgh. The entire thickness of limestone beds with some thin layers of interbedded shale is said to be 18 feet. Only 5 feet was visible at the time of our visit. A rather large amount could be obtained at that point without much stripping. Near the western terminus of the Ford City bridge there is an exposure of 6 feet of the limestone. Opposite Logansport the Upper Freeport was once quarried on a rather large scale and brought across the river by aerial tram to the railroad for shipment to the Pittsburgh furnaces as flux. It is 12 feet thick.

East of Allegheny River the Upper Freeport limestone is present only in small areas in the northern part of the county. Near the tops of the hills on either side of Mahoning Creek it has been observed in several places but is discontinuous. South of New Salem, several small quarries are located where it is about 3 feet thick, yet it has furnished stone for local agricultural use. In a few places it has been quarried in the hills near Goheenville. In several places in Wayne Township the Upper Freeport has been quarried but it is thin and discontinuous. It becomes more important to the south and has considerable value along the South Fork of Pine Creek. One mile south of Oscar the following section appears in a quarry worked by farmers in the vicinity to obtain stone for agricultural use.

Section of Upper Freeport limestone 1 mile south of Oscar

	Ft.	*in.*
Soil and sandstone	3	6
Clay and thin coal seam (6″)	5	0
Limestone	2	6
Shale		6
Limestone	1	0
Shale	2	0
Limestone	2	0
Fire clay		4
Limestone, compact, glassy fracture, exposed	5	0

Along Cowanshannock Creek the Upper Freeport is fairly continuous. On the south side of the creek about 3½ miles east of Kittanning the Upper Freeport has been quarried in a number of places and large amounts can be obtained without encountering heavy overburden. In one quarry where the overburden was approximately 6 feet the limestone layers aggregated 7 feet of typical Upper Freeport stone interbedded with shale beds amounting to 3 to 5 feet. One mile southeast of Greendale, the Upper Freeport is 8 to 12 feet thick. It lies about 12 feet below the Upper Freeport coal. Stone was quar-

ried here for more than 40 years, much of which was hauled many miles to be burned on farms where it was needed for fertilizing purposes. It was quarried on three farms in this locality. The ledge worked was traced eastward to near Yatesboro.

The Upper Freeport is of economic importance along Garrett and Rupp runs. Extending for several miles above the mouth of Garrett Run, it is thick and of good quality. The Ford City Lime & Coal Company operated a quarry along a small northern branch of Garrett Run where the following section was exposed.

Section exposed in Upper Freeport limestone quarry, Garrett Run

	Ft.	in.
Sandstone and shale	12	
Upper Freeport coal	3-4	0
White clay	3	6
Shale	4	6
Limestone	2	0
Shale		6
Limestone		10
Black shale	3	0
Typical Upper Freeport limestone, mainly thick bedded	8	0
Shale		

The limestone was burned and sold as hydrated lime. The lime was said to contain 59.6 per cent CaO and 2.2 per cent MgO. No large amount of stone can be obtained here without underground mining.

On Fort Run east of Ford City, Upper Freeport limestone has been quarried for flux, later for agricultural lime and to a limited extent pulverized in the raw state for fertilizing purposes. Much of the stone quarried has been burned in the open heap method. A large amount of stone might be obtained in this vicinity. Ed. Kunkel, Ford City, has recently quarried and burned limestone in this locality.

Section of Upper Freeport limestone exposed along Fort Run

	Ft.	in.
Surface soil	4-5	0
Impure limestone, breaks into thin layers	5	0
Shale	1	0
Siliceous limestone, massive	2	0
Bluish, compact, massive limestone	3-4	0
Drab shale	2	0
Bluish limestone ("Flat Dutch")	2	0
Drab shale	2	0
Irregular limestone, breaking into rounded boulders ("Niggers Head")	3	0
Shale		6
Heavy compact limestone ("Glass Rock")	3	0
Shale		6
Irregular gnarly limestone	3-4	0

In 1929 S. M. Hershberger & Son (Kittanning R. D. 1) were quarrying and burning Upper Freeport limestone along Rupp Run, 2 miles east of Manorville. They have 2 small kilns and burn about 600 tons of lime a year for agricultural use. An analysis of a sample from this point showed 93 per cent $CaCO_3$. The section of the quarry is as follows:

Section of Upper Freeport limestone, Rupp Run

	Inches
Gnarly blue stone	3½
Shale, bluish	2
Limestone, bluish	16
Limestone, bluish	20
Shale	4
Limestone, light blue	13
Shale	12
Shale, massive	23
Limestone, solid, hard, dark blue	16
Shale	3½
Massive, dove colored limestone, breaks with glassy fracture	41
Limestone, similar	13
Shale	6
Limestone	12

Elsewhere in this section the Upper Freeport has been dug on several farms in small quantities and burned in open heap for farm lime.

Along a small ravine about one-third mile southeast of McCain, the Upper Freeport limestone once furnished a large amount of fluxing stone for shipment to Pittsburgh furnaces. More recently much lime has been burned here. Much more stone could be quarried here.

Section of Upper Freeport limestone ⅓ mile southeast of McCain

	Ft.	in.
Overburden of soil and rotten shale	5-10	
Shaly limestone	2	6
Massive limestone	5	6
Bluish shale, sun cracks in upper layer	2	6
Limestone	4	0
Bluish shale	4	0
Massive, dense, brittle limestone	6	0

Between Ford City and Freeport, the Upper Freeport limestone seems to be practically continuous on both sides of Allegheny River. It has been most extensively worked near Logansport, Glen, and Kelly Station, where it is both thicker and of better quality. From the latter place to the mouth of Kiskiminetas River it is in places only about 4 feet thick.

Along Crooked Creek the Upper Freeport is exposed in only a few places and is probably discontinuous. Drill records show thickness of 5 to 11 feet. Just north of Tunnelville the Upper Freeport is said to be 6 feet thick at one place where it has been quarried for local use. An analysis of the upper 4 feet of the bed is given at the end of this section. Hughes (11, p. 137) gives the following section along a small tributary of Crooked Creek.

Section of Upper Freeport limestone, Crooked Creek

	Ft.	in.
1. Irregular, ferruginous nodular limestone	0	3
2. Massive limestone	3	0
3. Clay and limestone	0	6

4. Rounded, ferruginous, nodular limestone	0	4
5. Thin shaly limestone	0	2
6. Compact limestone	0	6

A composite sample, excluding layers 1 and 3, was analyzed and results are given at close of this section.

Along Plum Creek and Dutch Run in the vicinity of Elderton and along Sugar Run the Upper Freeport has been quarried on a small scale in a number of places. It ranges between 5 and 10 feet in thickness. Some locations are favorable for quarrying and could furnish a large quantity of stone.

Just east of Logansport there are quarries now largely filled with water where much fluxing stone was once obtained. Platt (2, p. 257) in 1880 gave the following section:

Section of Upper Freeport limestone, Logansport

	Ft.	*in.*
1. Limestone	1	7
2. Limestone, impure	0	8
3. Limestone	2	4
4. Limestone, impure	0	10
5. Clay and slate	1	3
6. Limestone, impure	0	7
7. Limestone, "Glassy layer"	5	6

Samples from beds 1, 4 and 7 were analyzed and results are given on a later page.

In the bluffs on both sides of Taylor Run at Kelly Station and in the river bluffs between Kelly Station and Glen considerable Upper Freeport limestone has been obtained at the outcrop. It ranges from 8 to 10 feet in thickness including some thin interbedded shales. There is an abundance of stone in this section and quantities might be obtained without unduly heavy stripping.

Except about 1½ miles above Apollo, the Upper Freeport limestone is of little value along Kiskiminetas River in Armstrong County. In 1902 a company was organized to promote the building of a cement plant at this point. It was not built, however, and later the deposit was worked for a number of years to obtain stone for ballast and for lime burning. It was in operation in 1919 when visited by the writer but has since been closed. The ledge worked outcrops about 160 feet above the river. Where observed, the limestone ranged in thickness from 10 to 12 feet but the superintendent maintained that in places it is 20 feet thick. One layer of interbedded fire clay from 1 to 3 inches thick was noted; otherwise the entire thickness consisted of limestone. Fire clay underlies the limestone and 7 feet of shale lies above. The ledge has several rolls and in places dips as much as 8 to 10 degrees.

Near the outcrop the limestone is buff in color but the unweathered stone is dark blue. It is dense, brittle and without fossils. On account of its brittle character an excessive amount of fine material was produced by the crushing. The rock was obtained by underground mining. Rooms 26 feet in width were driven every 45 feet. The shale roof held up well so that little timber was used. However in the main entries part of the limestone was left for a roof. The

broken stone was hauled by mules to the mine entrance and thence let down by cable to the crusher near the railroad.

In 1919 the company was producing about 500 tons of crushed stone daily, all of which was taken by the State Highway Department for roads in Westmoreland, Allegheny, and Indiana counties. It was planned to pulverize some of the limestone for agricultural uses and to revive burning of lime. The plant was well located and was connected with the railroad at Apollo with a branch line. The supply of stone is large at this point but evidently the company was unable to compete with other companies operating open quarries.

In the prospectus issued by the cement company many analyses of the limestone are given. Several of these are included in the table on a later page. The chemist in charge stated that the limestone analyzed averaged 91.76 per cent $CaCO_3$. Inasmuch as it was proposed to use the shale overlying the limestone for the cement mixture, four shale analyses are given.

Analyses of shales associated with Upper Freeport limestone 1½ miles above Apollo

	1	2	3	4
Loss on ignition	6.75	6.10	13.80	5.37
SiO_2	65.81	65.94	65.35	69.83
Al_2O_3	16.25	21.57 }	5.34	16.91*
Fe_2O_3	7.20	5.10 }		4.93
CaO	2.56	1.38	14.85	None
MgO	.48	.85	1.10	1.02

* Contains TiO_2

Analyses 1, 2 and 3 by L. E. Allen. No. 4 by Booth, Garrett & Blair.

An examination of these analyses shows a rather high silica content in proportion to the iron and alumina, yet it is not improbable that some shale might have been found in the vicinity that, mixed with the limestone, would make satisfactory Portland cement. However, it is doubtful whether the economic situation would justify the erection of a cement plant at this point. Other factors than the supply of raw materials should receive careful attention.

Analyses of Upper Freeport limestones from Armstrong County

	1	2	3	4	5	6
SiO_2	7.40	7.78	1.75	1.80	4.88	4.94
Al_2O_3	.93	3.68 }				
FeO, Fe_2O_3	1.29	4.00 }	2.75	2.60	3.20	3.60
CaO	48.39	43.57	53.27	53.19	50.95	49.83
MgO	1.30	1.93	.70	.67	.60	.75
TiO_2	.10	.20				
Loss on ignition	40.20	33.88	42.15	42.20	40.82	40.52
Total	99.61	95.04	100.62	100.46	100.45	99.64
$CaCO_3$	86.41	77.80	95.12	94.94	90.98	88.98

	7	8	9	9a	10	11	12
SiO_2	5.12	4.36	1.75	5.65	.73	2.93	4.04
Al_2O_3					.42	.25	.50
FeO, Fe_2O_3	3.18	3.40	2.75	4.90	1.95	1.41	1.72
CaO	50.45	50.65	53.27	48.10	53.88	52.17	51.00
MgO	1.18	1.55	.70	.78	.26	.64	1.09
TiO_2							Trace
Loss on ignition	39.92	39.10	42.15	40.12	43.11	42.40	41.62
Total	99.85	99.06	100.62	99.55	100.35	99.80	99.97
$CaCO_3$	90.08	90.44	95.11	85.82	95.76	93.16	91.07

	13	14a	14b	14c	15
SiO_2	9.520	.830	2.200	3.170	5.030
Al_2O_3 and Fe_2O_3	2.568	.964	1.340	1.207	2.557
$CaCO_3$	84.857	96.453	93.214	93.571	88.839
$MgCO_3$	1.868	1.445	2.065	1.324	1.513
P	.024	.007	.004	.029	.021
Total	98.837	99.699	98.823	99.301	97.960

	16	17	18a	18b	18c
SiO_2	1.920	1.850	4.830	7.310	4.520
Al_2O_3 and Fe_2O_3	1.246	1.182	2.002	3.367	1.860
$CaCO_3$	94.928	94.642	89.303	82.589	89.857
$MgCO_3$	1.210	1.574	1.900	5.751	2.898
P	.018	.012	.021	.063	.017
Total	99.322	99.260	98.056	99.080	99.152

1. Analysis of upper 4 feet of Freeport limestone from farm of T. C. Miller, north of Tunnelville. Analysis by Pittsburgh Testing Laboratory.

2. Analysis of composite sample of Freeport limestone ledges 2, 4, 5 and 6 of section given on page 48. Bed of small stream tributary to Crooked Creek, west part of Burrell Township. Analysis by Pittsburgh Testing Laboratory.

3–6. Proposed cement quarry location, 1½ miles above Apollo. Analyses by L. E. Allen.

7. Proposed cement quarry location, 1½ miles above Apollo. South side of Roaring Run. Analysis by L. E. Allen.

8. Proposed cement quarry location, 1½ miles above Apollo. North side of Roaring Run. Analysis by L. E. Allen.

9. Proposed cement quarry location, 1½ miles above Apollo, lighter stone. Analysis by L. E. Allen.

9a. Proposed cement quarry location, 1½ miles above Apollo, darker stone. Analysis by L. E. Allen.

10–11. Proposed cement quarry location, 1½ miles above Apollo. Analyses by Booth, Garrett & Blair.

12. Proposed cement quarry location, 1½ miles above Apollo. Analysis by Pittsburgh Testing Laboratory.

13. Freeport Upper limestone. From W. R. Hamilton's land near the coal mine, 1½ miles north from Putneyville. Fine grained, tough; dark gray (3, p. 83).

14. Freeport Upper Limestone. Mehaffey & McGill's quarry, Armstrong County. Quarry is ¾ mile east from Logansport. (a) Top layer is fine-grained and brittle; dark pearl gray. (b) Second layer is fine grained; tough; dark pearl gray. (c) Bottom layer is very compact and fine-grained; hard and tough; light pearl gray with conchoidal fracture (3, p. 84).

15. Freeport Upper limestone. John Reefer's quarry, Armstrong County, 3 miles southwest of Rural Valley. Fine grained; tough; mottled with calcite; dark gray; fracture conchoidal (3, p. 84).

16. Freeport Upper limestone. Wm. Marshall's quarry, 1 mile east of Dayton. Fine grained; tough; mottled with calcite; dark gray (3, p. 84).

17. Freeport Upper limestone. S. Monroe's quarry, Armstrong County, 2 miles southwest of Slate Lick. Fine grained; tough; dark pearl gray (3, p. 84).

18. Freeport Upper limestone. A. J. Dull & Co., Armstrong County. Quarries in the ravine of Fort Run, near Manorville. (a) Upper layer very compact and fine grained; dark pearl gray; with conchoidal fracture. (b) Second layer is fine-grained; hard and tough; somewhat argillaceous; dark pearl gray, with conchoidal fracture, small crystals of pyrite throughout the specimen. (c) Third layer is very compact and fine-grained; slightly mottled with calcite; pearl gray, with conchoidal fracture (3, p. 84).

LIMESTONES OF THE CONEMAUGH GROUP

Brush Creek limestone. There is little to be said concerning any of the limestones of the Conemaugh group in Armstrong County. Where recognized, they are local, thin and generally decidedly impure. In a few places a thin limestone rather closely associated with the Brush Creek coal has been correlated with the Brush Creek limestone. It is of no value.

Ames limestone. The Ames limestone has been definitely recognized near the tops of three hills in North Buffalo Township. On the farm of J. M. Rea, 1½ miles northwest of Slate Lick, it is exposed as a greenish-gray, impure limestone containing abundant crinoid stems and other fossils. It is 2 to 3 feet thick. Similar exposures were seen ½ mile and 1½ miles northeast of Sisterville. A limestone about 1 foot thick and similar in appearance has been noted east of Allegheny River. So far as known no use has ever been made of the Ames limestone in Armstrong County.

Pittsburgh limestone. The Pittsburgh limestone is not known to occur in Armstrong County other than in a small area near Olivet. In a small ravine about 1 mile east of Olivet it was at one time quarried on a small scale for lime burning. The place was visited but only about 8 inches of shaly limestone could be seen. It is said to be about 5 feet thick and is described as fairly pure, compact, brittle and moderately heavily bedded. It is dark bluish-gray when fresh but becomes lighter in color on weathering. It is probably of some local value.

LIMESTONES OF THE MONONGAHELA GROUP

Sewickley limestone. The limestones of the Monongahela group are of little importance in Armstrong County because of their slight areal distribution in the southeastern part of the county. One is described in the Elders Ridge Folio as follows (8, p. 6):

"Above the Redstone coal for 45 feet the rocks are shale with some thin sandstones and arenaceous shales which are so soft that they weather deeply. A limestone which averages 6 feet thick occurs at the top of this interval. It is fossiliferous fairly pure, sometimes has a brownish cast, and is easily calcined. It is exposed in the bluff on the river and has been opened in a ravine at Olivet. So far as known it has not been explored elsewhere and its exposures are few. The name commonly given to this member of the formation is Sewickley limestone."

Benwood limestone. The Benwood limestone is present in a limited area near Elders Ridge, capping the top of at least one hill. It has not been observed by the writer in Armstrong County but a small amount may be present. It is of some local value in Indiana County and is briefly described in that portion of the volume.

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BEAVER COUNTY

There are several different limestones in Beaver County but all of them are extremely variable in thickness and composition. No one is persistent throughout the county and any one may decrease from its maximum thickness to its complete disappearance within a few miles. The Vanport is the only bed of real importance but it is much less valuable than in the counties lying to the north and northeast of Beaver, largely because of its irregular distribution and variable thickness. In recent years very little limestone has been quarried in the county.

Geological section of Beaver County

Monongahela group
- Pittsburgh sandstone
- Pittsburgh coal

Conemaugh group 500±
- *Upper Pittsburgh limestone*
- *Lower Pittsburgh limestone*
- Connellsville sandstone
- Little Clarksburg coal
- *Clarksburg limestone*
- Morgantown sandstone
- Barton coal
- *Barton limestone*
- Birmingham shale
- Berlin coal
- *Ames (crinoidal) limestone*
- Friendsville (Harlem) coal
- Saltsburg sandstone
- Bakerstown coal
- *Pine Creek (Upper Cambridge) limestone*
- *Brush Creek (Lower Cambridge) limestone*
- Brush Creek coal
- Mahoning sandstone

Allegheny group
- Upper Freeport coal
- *Upper Freeport limestone*
- Butler sandstone
- Lower Freeport coal
- *Lower Freeport limestone*
- Freeport sandstone
- Upper Kittanning coal
- Middle Kittanning coal
- Lower Kittanning coal
- *Vanport (Ferriferous) limestone*
- Bolivar sandstone
- Clarion coal
- Clarion sandstone
- Brookville coal

Pottsville series
- Homewood sandstone

In the section only the named beds are included; many shale and sandstone strata are omitted. Of the limestones those above the Ames are seldom identified and some may possibly be absent altogether.

LIMESTONES OF THE ALLEGHENY GROUP

Vanport limestone. In Beaver County, as well as the other counties in western Pennsylvania containing this limestone, the Vanport is the most valuable limestone present. Although it receives its present name from a small town of this county, it is of much less importance in Beaver County than in Lawrence, Butler and Armstrong counties. In general it is thinner, is exposed in fewer places readily accessible to mining or quarrying, appears to be less pure on an average, and is much more variable in thickness. It is not unusual to find it varying from its maximum thickness to an unworkable thickness, or altogether disappearing within a very few miles. One or more of these factors have prevented the development of any important limestone industry within the county, although small and yet profitable quarries have been opened and worked in a number of places.

In those localities where the Vanport thins it is almost invariably found to be inferior in quality and to show cone-in-cone structure.

Everywhere it is rich in fossils belonging to many different classes of organisms. Normally it lies about 65 feet below the Kittanning coal.

The outcrops of the Vanport in Beaver County are almost entirely confined to the Beaver River and tributaries and to the Ohio River valley below Freedom. One of the best developed occurrences is that at Vanport.

Section of Vanport limestone at Vanport

	Ft.	in.
Blue limestone	4	0
Shale		4
Light gray to blue limestone	8	0
Shale		6
Limestone		6
Shale	2	2
Hard ferruginous limestone	1	0
Shale		6
Fossiliferous limestone	2	0
	19	0

In this locality the upper portion (9 inches to 1 foot) of the 4-foot bed had to be discarded by the lime company formerly working the quarry. The remainder of this bed and the 8-foot bed were used for lime, producing a high quality white lime. The thinner beds beneath were too impure to be used, but would furnish satisfactory crushed stone.

In 1929, Richard Wilson worked a small quarry a short distance to the west of the above locality to obtain stone to pulverize for fertilizing purposes. The section is slightly different.

Section in Richard Wilson quarry, Vanport

	Ft.	in.
Gnarly, or knotty, gray limestone breaking on weathering into beds about 1½ inches thick	3	6
Shaly layer, containing some limestone, deeply stained by ferruginous matter	0	6-12
Gnarly blue to light dove-colored limestone which breaks on weathering into thin beds ¾ to 1½ inches thick, exposed	7	0

Westward from Vanport, the limestone thins rapidly and is seldom exposed, due principally to the heavy deposit of terrace gravels that fill the valley. The only exception is on the south side of the river opposite Montgomery Island where a 12-foot thickness of stone was one time quarried. Near the Ohio line it is about one foot thick, impure and shows cone-in-cone structure.

Along Ohio River above Vanport, the Vanport also thins. At Rochester it is about 5 feet thick. Along Beaver River a short distance above Rochester a thickness of 8½ feet has been recorded at one place where it was once quarried and burned but of this thickness 4½ feet consisted of interbedded shale layers. In a locality near Blockhouse Run, where the bed is 3 feet thick, it was once quarried and used in the manufacture of cement for the construction of the locks of the old Erie and Pittsburgh canal. On Whistlers Run it is 2 to 3 feet thick and the same is true at a number of exposures in the neighborhood of New Brighton. On Big Beaver above New Brighton it con-

tinues thin and seems to be absent in the vicinity of Homewood. It appears again south of the Lawrence County line and south of Ellwood City almost on the county line the Clydesdale Brick Co. (Crescent Brick Co.) formerly worked a quarry for lime burning.

Section at quarry of Clydesdale Brick Co., Ellwood City

	Feet
Gray limestone, massively bedded but breaking into thin layers on weathering	6-7
Hard massive bed called the "Bull Layer"	1
Blue limestone, breaking into thin beds on weathering, top somewhat shaly	15
Shale	

With the increase of overburden quarrying was abandoned for underground mining. Five tunnels, the longest of which is about 350 feet, were run into the hill. About 7 years ago, the limestone operations ceased and only the overlying shale has been quarried for the brick plant. A large area of stone, several acres in extent, has been uncovered. This could be easily quarried but the company fears that blasting it might result in damage to the brick kilns.

Lower Freeport limestone. Wherever the Lower Freeport limestone has been reported in Beaver County, it is thin, impure and altogether of little economic significance. Nevertheless in the days of poor transportation facilities, it was quarried and burned for agricultural lime in a number of localities. It is light gray, in many places prominently brecciated, and breaks with a conchoidal glassy fracture. It is nonfossiliferous. It commonly contains a rather large proportion of ferruginous matter either in the form of iron nodules or in fine indistinguishable particles. The reports are that it made a fairly good lime but was difficult to slake.

Near Baden the Lower Freeport limestone is 2 feet thick and was once quarried and burned. Similar use was made of it along Crows Run in North Sewickley Township where it is 3 feet thick and in Franklin Township where it is 4 feet thick and quite ferruginous. Near Homewood it consists of two layers, the upper 1½ feet and the lower one 2 feet thick, separated by a 2-foot bed of shale. In South Beaver Township it is 3 feet thick and was once burned but the lime did not slake well.

Its distribution and characteristics in the Beaver quadrangle are described in the following paragraphs from the Beaver Folio:

"This is the next higher limestone which is of any value within the quadrangle and its horizon is a few feet below the coal from which it is named. Because of the southward dip of the rocks, this horizon is exposed chiefly in valleys of the northern half of the quadrangle, those in the southern portion incising it little. Compared with the Vanport limestone it is very impure, being usually a hard, fine-grained, nonfossiliferous rock of buff color, and it is of little value in the greater part of the quadrangle. Its common mode of occurrence is that of isolated lenses and it is therefore absent in many localities. Indeed, within this area only three lenses of workable dimensions were found. Of these the most extensive lies along the northern edge of the quadrangle, including Beaver Valley in the vicinity of Beaver Falls, Brady Run, and the northward-facing valleys in the northwest corner of the quadrangle. In this general area the limestone ranges

in thickness from 3 to 9 feet, averaging 6 feet. The outcrops of two smaller lenses were discovered—one northwest of Smiths Ferry in the lower course of Island Run and the other south of Monaca in the run west of Hog Island. In both runs the limestone occurs from 4 to 5 feet thick.

"This limestone is in places pure enough to produce lime for fertilizer, and for such limited purposes it may be quarried in almost any locality where it occurs, especially in the northwest portion of the quadrangle."

Upper Freeport limestone. The Upper Freeport limestone outcrops in the sides of the stream valleys in almost all parts of the county. The average thickness is 2½ to 3 feet. In most localities it consists of several beds separated by shale or fire clay. Typically it is a light-gray, compact, non-fossiliferous limestone. Locally it has been used in many places for agricultural lime where it could be easily quarried, more in the past than in recent years. It possesses only slight local value.

Its occurrences in the Beaver quadrangle have been described as follows in the Beaver Folio (7, p. 14).

"This limestone lies a few feet below the Upper Freeport coal, and, like the lower Freeport limestone, occurs chiefly in the northern portion of the quadrangle. It is usually impure, being buff colored or ferruginous, but occasionally it is a bluish rock of pure quality. In many cases it is brecciated and generally it is nonfossiliferous.

"This limestone, following the usual habit, occurs in lenses but unlike the other limestones these lenses seem smaller and more numerous or are connected by very thin beds. Thus on the line of outcrop stretches of limestone thick enough to be of economic importance alternate in short distances with thin beds or with horizons in which it is absent.

"In general, localities likely to reveal thicknesses worth exploiting are Blockhouse and Brady runs, 2 to 3 feet; the northward-facing valleys along the northwest margin of the quadrangle, 4 to 6 feet; head of Dry Run, 2 to 7 feet; west of Hog Island, 3 feet; Monaca, 5 feet; and mouth of Raccoon Creek, 4 feet. Though the limestone may be as thick as this at other localities where it is concealed, all other observations recorded its absence or thinness.

"This bed, like the Lower Freeport limestone, occurs high in the rocks and hence is not conveniently accessible along the steep sides of deep valleys like those of Ohio and Beaver rivers. Near the heads of small streams, however, it may be easily approached.

"Wherever the purer blue rock is found it may burn to a fair strong lime, but elsewhere it is good only for common fertilizer, if for that."

The Upper Freeport limestone is about 3 feet thick along Tevebau Run in Economy Township and consists of two layers, the upper one shaly and the lower compact gray limestone. Along Crows Run in New Sewickley Township it is 2 feet thick. In North Sewickley Township it is 2½ to 4 feet, has been quarried for lime burning, and is a good quality lime. It is 4 feet thick, light gray, compact and hard in places in Franklin Township. At Homewood it consists of 5 to 6 layers interbedded with shales and clay, the whole aggregating 10 feet thick. It has been quarried and burned at Darlington where it is a light-gray, compact rock 3 feet thick. At points in South Beaver and Chippewa townships it is 2½ to 3 feet thick.

LIMESTONES OF THE CONEMAUGH GROUP

Brush Creek limestone. The Brush Creek limestone has been recognized in several places in Beaver County and is doubtless present in many other localities besides those reported. It is an impure sandy to shaly limestone, in places having a pinkish tint because of its iron content, elsewhere dark to black due to high carbonaceous content, and in some localities dark gray. It contains many fossils, crinoids, brachiopods, etc. Near Wall Rose in Economy Township, it is 1½ feet thick, near Economy 4 feet, and near Smiths Ferry 1 foot.

Pine Creek limestone. The Pine Creek limestone has been reported from only a few places in Beaver County. Wherever noted it is a dark-grayish, hard, sandy, impure limestone containing many fossils. It is of no economic importance. Near Wall Rose in Economy Township it is 2½ feet thick; about half a mile above Smiths Ferry it is 2 feet.

Ames limestone. The Ames limestone is extensively developed in the southern part of Beaver County and is so persistent that it can be used as a key rock in working out the structure of the region. Woolsey described it as follows (7, p. 7):

"This stratum may be taken as the approximate middle of the Conemaugh formation, for in this district it averages 290 feet above the Upper Freeport coal and 230 feet below the Pittsburgh seam. These intervals in reality vary from 20 to 25 feet in either direction. It is the most persistent member of the formation and is present not only throughout the southern half of the quadrangle but throughout several counties in Pennsylvania and Ohio. In not more than six localities where it has been diligently sought has it proved to be absent. It seems to retain its peculiar lithologic character wherever known, and can therefore always be readily recognized. Stevenson, in his report on the Greene and Washington district (2, p. 80) describes it as 'dark bluish or greenish gray, tough,' and breaking with a 'granular surface, much resembling that of a coarse sandstone.' The weathered rock has a peculiarly rough aspect, due to small protuberances of crinoid stems, with which it is crowded. The general effect, in fact, is very far from the usual appearance of a limestone. Besides the multitude of crinoidal fragments, the other fossils are chiefly brachiopods and gastropods.

"North of Ohio River in the Beaver quadrangle this limestone is scarcely seen, occurring only as the cap of a small knob on the Lisbon road 3½ miles east of Blackhawk, and as eight small patches on the summits of the river hills west of Industry. South of the Ohio the patches become larger and more numerous, as at McCleary, Green Garden, and Bunker Hill, until finally as it dips lower, it makes one continuous though irregular blanket over the southern third of the quadrangle. Its ordinary occurrence is that of a single bed, but in a few instances there seem to be two separate beds of this limestone. This is notably so on the western edge of the quadrangle, opposite Hookstown, where the interval between the two beds is 31 to 35 feet.

"The persistent bed has a thickness varying from 1½ to 6 feet, but averaging about 3 feet. Typical exposures may be seen at Harshaville, south of Green Garden, on Bunker Hill, and north of Hookstown."

Although the Ames is everywhere an impure limestone, it was

quarried and burned for agricultural lime in a few places many years ago. There is a statement, frequently heard, to the effect that the crinoid stems have been picked out and used to make a cement employed locally for household use.

Other limestones of the Conemaugh group. The other limestones listed in the geological section are of no importance and have rarely been recognized. They are thin non-persistent strata in Beaver County.

A limestone locally developed but which has not received a distinctive name is described as follows (7, p. 14):

"This bed occurs as small lenses in the Mahoning sandstone about 30 feet above the Upper Freeport coal, and evidences of it have been seen at several places in the quadrangle. A valuable thickness, however, was observed only east of Rochester, where it is 5 to 8 feet. Here it has the bluish-gray color of a remarkably pure limestone and has been quarried to some extent. In other instances it is often impure and ferruginous, outcropping as a thin bed or a few fragments."

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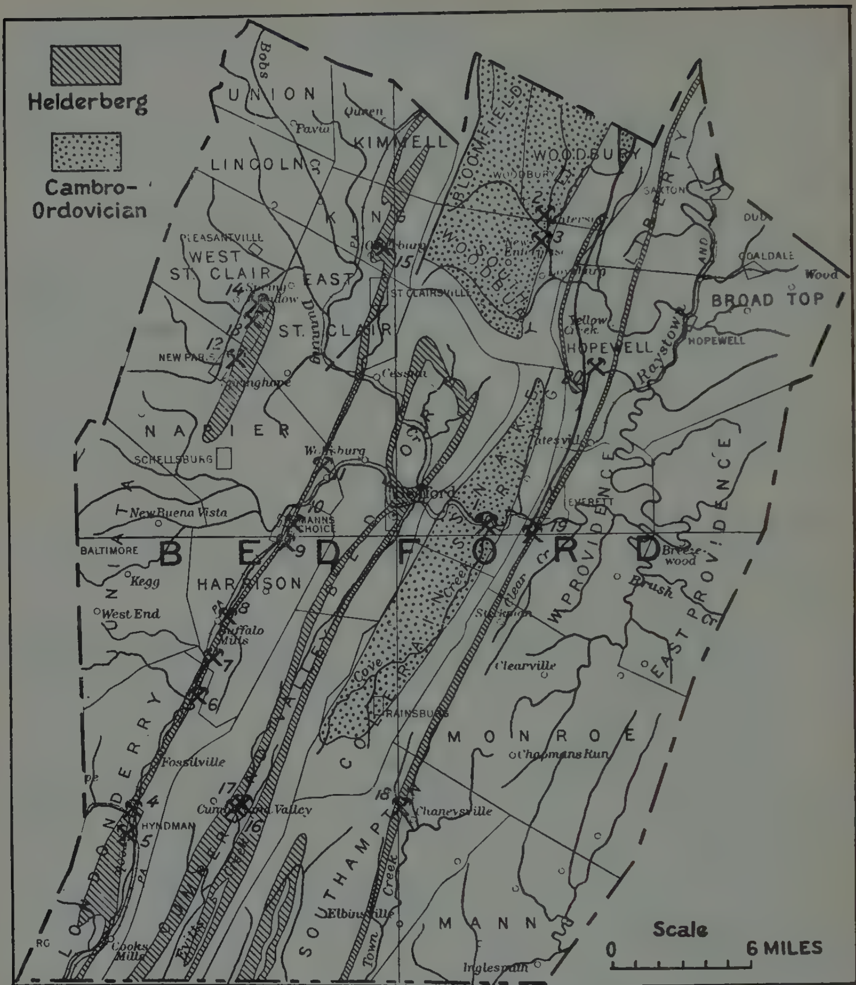

Fig. 8. Limestone areas in Bedford County.

1. Everett-Saxton Co.
2. New Enterprise Lime and Stone Co.
3. J. S. Longenecker
4. Enterprise Lime and Ballast Co.
5. Peerless Lime Co.
6. Russell Mowry
7. G. B. Carpenter and R. E. Barkley
8. A. B. Robertson
9. C. E. Shilling
10. Daniel Hillegas
11. State Highway Department
12. J. S. Taylor
13. Dorsey S. Ling
14. Madison Horn
15. G. G. Exline
16. A. B. Valentine
17. John R. Cussins
18. Ford Browning
19. A. M. McClure
20. Marshall L. Ritchey

BEDFORD COUNTY

Bedford County lies within the zone of greatly folded rocks of the Appalachian Valley. High and rather narrow mountain ridges, trending slightly west of south and composed of hard, resistant sandstones, separate narrow longitudinal valleys occupied by limestones and shales. The mountain ridges rise 800 to 1,500 feet above the valleys. From the Allegheny Front on the western border the most prominent ridges are Buffalo, Wills, Dunning, Evitts, Tussey and Broad Top. Numerous other shorter and lower ridges are present. The topography is varied but in general is so rough that some say there is no area of level land of 10 acres extent in the entire county. The major streams have cut through the main mountain ridges in several places, thus facilitating railroad and highway transportation in an east-west direction. The minor streams and the branch highways and railroads follow the north-south narrow valleys.

The rock strata of Bedford County are varied in character and age. They consist entirely of sedimentary rocks and range from the Cambro-Ordovician to the upper portion of the Pennsylvanian. Little detailed stratigraphic work has been done within the county since 1882 so it is not possible to give a geologic column with the present recognized and accepted divisions. The larger groups of limestones are therefore discussed as units, even though it is well recognized that each of the groups consists of a number of different kinds of strata, some of which are of economic importance and others valueless. The descriptions which follow furnish information which should enable one to judge whether limestones of particular kinds are present or not, but additional detailed data should be collected before reaching a decision concerning the advisability of opening a quarry in any designated locality. The structure of the strata is such as to call for careful geologic work. In many places trenching or drilling is necessary in order definitely to determine the real economic situation.

The limestone industry of Bedford County in recent years has been confined almost entirely to large operations at Ashcom, Hyndman and Waterside, although there are small plants in a number of different places. Scores of abandoned small quarries indicate that at an earlier date many more quarries were in operation, although in each case the output was small and limited to local demands for lime and building stone.

The limestones of Bedford County mainly belong to the Cambro-Ordovician series and the Helderberg, but include some limestones in the Upper Devonian above the Helderberg, and some in the Carboniferous. They will be discussed in these four groups.

CAMBRO-ORDOVICIAN LIMESTONES

The oldest limestones of Bedford County belong to the thick series of Cambro-Ordovician sediments. With the exception of two small patches on Buffalo Mountain, northeast and southeast of Buffalo Mills, these limestones are confined to that part of Morrison Cove included within Bedford County and to a similar cove or wide valley on the

south, known as the Cove or Friends Cove, but separated from Morrison Cove by a sharp bend in Evitts Mountain that brings it in near contact with Tussey Mountain. The latter mountain bounds both of these broad limestone valleys on the east, with Evitts and Dunning mountains forming the western boundary. The limestone area in Morrison Cove is approximately 9 miles long and 4 miles wide and is drained by Yellow Creek and its tributaries. Raystown Branch of Juniata River cuts across the southern cove valley and receives Snakespring Valley Run from the north and Cove Creek from the south. These two tributary streams collect practically all the drainage of this longer valley which is floored with limestones for a length of about 15 miles and an average width of approximately 3 miles.

The Cambro-Ordovician limestones of the southern cove have been worked in many places but only one operation, the largest in the county, is of real importance. This is the quarry and plant of the Everett-Saxton Co. at Ashcom, about 2½ miles west of Everett. This is the quarry formerly worked by the Joseph E. Thropp Iron Co. For many years this quarry supplied fluxing stone for the iron furnaces at Everett, but more recently the product has been used for a number of purposes. The best grade of stone is burned for lime, part of which goes to the chemical trade and the balance for plastering and farm use. It is sold as lump, pebble, and hydrate. There are 3 kilns. Some of the limestone is pulverized raw and sold for mine dusting and for agricultural use. This stone is dried in a rotary drier and then pulverized in a rotary ball mill. For mine dusting it is reduced to pass through a 60-mesh screen and for farm use through a 20-mesh screen. Crushed stone for highway construction and as concrete aggregate for any purpose is also produced. The crushed stone is in general obtained from those layers that are higher in SiO_2, Al_2O_3 and Fe_2O_3. The annual production is given as 300,000 tons of crushed stone, 100,000 tons of blast furnace flux, 9,000 tons of lime, and 9,000 tons of pulverized limestone.

The several kinds of stone in the quarry are shown in the following section:

Section in Everett-Saxton quarry, Ashcom

	Feet
Dark blue, more or less gnarly limestone	45
Compact, blue limestone breaking with a conchoidal, glassy fracture, good quality stone	10
Dark blue, gnarly rock with shale partings	12
Blue, thin-bedded limestones	20
Dark blue, gnarly rock, ripple marked	6
Light blue (calico), dense rock, breaks with glassy, conchoidal fracture, contains numerous caves in places ..	30
Dark blue rock, rather highly siliceous	8
Dark blue rock less siliceous than overlying beds	10
Dark blue, compact stone, good quality	20
Sandy limestone blotched with limonite on weathered surface	

The strata worked seem to belong mainly to the Black River group of limestones but include some of the Trenton. The quarry is being advanced to the south along the strike which is S37°W. The beds dip SE at angles ranging from 40° to 45°, and less toward the east face. The width of the quarry is 170 feet and the depth at the face

about 144 feet. It is being worked in two benches, the upper one 97 feet high and lower one 47 feet. The company has sampled the quarry in 22 ledges beginning at east (upper strata) and going west. The samples were analyzed for SiO_2 and R_2O_3 (Al_2O_3 + Fe_2O_3). The balance is $CaCO_3$ and $MgCO_3$. Where the SiO_2 and R_2O_3 together amount to 5 per cent the company states that the $CaCO_3$ averages a little less than 91 per cent and $MgCO_3$ a little over 4 per cent. The results are as follows:

Analyses of limestone strata in Everett-Saxton quarry, Ashcom

Ledge	1	2	3	4	5	6	7	8	9
SiO_2	2.30	5.50	6.65	5.50	5.15	9.40	7.00	2.35	1.80
$Al_2O_3+Fe_2O_3$	1.50	3.40	2.80	1.50	3.50	3.65	3.65	1.45	1.60

Ledge	10	11	12	13	14	15	16	17	18
SiO_2	2.70	1.55	3.30	4.10	2.10	1.50	1.55	1.30	1.40
$Al_2O_3+Fe_2O_3$	.65	.65	1.50	2.05	.95	1.90	.90	1.55	1.35

Ledge	19	20	21	22
SiO_2	3.50	2.05	1.55	4.20
$Al_2O_3+Fe_2O_3$	2.00	1.50	2.00	5.10

Twelve ledges of underlying rock farther west adjoining the quarry were also sampled and analyzed with the following results. These show rock high in magnesia, alumina and ferric oxide although there are some layers of good limestone.

Analyses of limestone strata adjoining Everett-Saxton quarry, Ashcom

	1	2	3	4	5	6
SiO_2	10.50	7.00	12.30	1.30	3.00	4.80
$Al_2O_3+Fe_2O_3$	8.00	7.50	5.30	2.65	11.30	15.50
$CaCO_3$	53.57	56.07	50.00	93.21	66.07	66.43
$MgCO_3$	27.30	29.40	32.02	3.04	19.05	12.60

	7	8	9	10	11	12
SiO_2	4.50	3.25	.55	3.90	4.80	4.30
$Al_2O_3+Fe_2O_3$	6.50	6.80	.50	11.50	11.10	8.75
$CaCO_3$	72.32	74.11	94.50	69.11	66.07	62.05
$MgCO_3$	16.78	15.62	6.40	16.80	17.54	24.78

South of Ashcom the Cambro-Ordovician limestones are continuous in the valley in which the villages of Otttown, Diehl, Charlesville, and Rainsburg are located. Stone is said to have been formerly quarried here in scores of places by the farmers for local use but in 1929 no quarries were being worked. Some stone for highway

use has been obtained here in recent years. There are many places where stone well adapted for crushed stone might be readily obtained and there is little doubt but that careful search might reveal ledges of the same character as those utilized at Ashcom. Most of the limestones are fairly high in magnesium but some are distinctly low.

Similar statements to the above may be made with reference to Snakespring Valley, lying north of Raystown Branch of Juniata River, and drained by Snakespring Valley Run.

That part of Morrison Cove lying within Bedford County and comprising Bloomfield, Woodbury, and South Woodbury townships has an abundance of Cambro-Ordovician rocks easily obtainable. It is said that at one time or another some limestone quarrying has been done on practically every farm. Most of these quarries were opened to get stone for burning for agricultural lime, but many of them have furnished building stone. There are numerous attractive stone houses throughout the region that have been built of local limestone. From time to time even now farmers dig some stone on their farms for their own use. The building of hard roads in recent years has been facilitated in this region because of the easy accessibility of thoroughly satisfactory stone.

The most important operation in Morrison Cove in recent years is that of the New Enterprise Lime & Stone Co., one mile south of Waterside. The quarry is operated the entire year to obtain stone for lime burning, and crushed stone is made when there is a demand for it. The stone is satisfactory both for crushed stone and for lime, and both products are in local demand. The lime is sold to the farmers for application to the soil.

The quarry contains several different kinds of stone. The color ranges from gray to bluish black, the gray being high grade and the darker bands containing more magnesium and silica. All kinds become white on weathering. Some layers contain numerous fossils, especially crinoids. Some layers show stylolites and edgewise conglomerate structures. The stone worked is in thick beds, some as much as 20 feet. Overlying the strata being worked are thinner limestones. The strike is N20°E, dip 32°SE. Clay seams are rather numerous, some as much as 2 feet in width. Some of them follow bedding planes but others cut across the beds. Cave deposits are rather prominent where water passing through the rocks has first enlarged the openings and later deposited some calcareous matter. The clay seams and cave deposits probably decrease in depth. The quarry face is about 60 feet high.

The company has two kilns. Coal for burning comes from the Broad Top mines. The annual production is given at 5,000 tons of lime and 75,000 tons of crushed stone.

On the west side of Yellow Creek about one mile north of Waterside is the J. S. Longenecker quarry which was worked for crushed stone for highway use a few years ago. The face is about 100 feet long on the strike, but shows only about 15 feet of strata. The strike is N37°E, dip 22°SE. Weathered surfaces show excellent suncracks. The layers are rather thin and consist of hard, fine-grained, compact, dolomitic material interbedded with coarse-grained, gray, high-lime beds containing abundant fragmental fossils. The horizon of the beds of this quarry appears to be lower than that worked

by the New Enterprise Stone & Lime Co. about 2½ miles to the south. Considerable chert in layers 2 to 3 inches in thickness was observed in the dump but was not seen in place.

In general it may be said that the Cambro-Ordovician limestones of Bedford County represent a great thickness and a wide variety of material. It is rather doubtful whether stone of the high quality obtained in the Bellefonte district of Centre County is present but careful search and, possibly, drilling may reveal the presence of even better stone than thus far utilized. For the manufacture of lime of various kinds and for crushing there is an abundance of stone.

Additional analyses of Cambro-Ordovician limestones of Bedford County

	1	2	3	4	5a	5b	6
$CaCO_3$	69.107	93.014	90.857	85.892	64.75 to 91.05	78.81	51.964
$MgCO_3$	23.951	3.329	3.216	10.637	3.96 to 27.85	15.43	40.032
SiO_2	-------	-------	-------	-------	2.34 to 4.70	3.77	-------
$Al_2O_3+Fe_2O_3$	.542	.394	.360	.410	.70 to 2.16	1.43	1.270
S	.266	.046	.103	.075	.07 to .15	.10	.016
P	.008	.002	.006	.005	.003 to .010	.007	.004
Insoluble	5.790	3.660	5.130	3.090	-------	-------	6.420

1. Farm of J. Carper, Woodberry Township. 2, pp. 335-336.
2. Farm of J. Brumbaugh, South Woodberry Township. 2, pp. 335-336.
3. Farm of M. Kagarise, South Woodberry Township. 2, pp. 335-336.
4. Farm of D. Dunkle, Snake Spring Township. 2, pp. 335-336.
5. Steel and Koontz property near Ashcom, Snake Spring Township. 7 samples, a. range, b. average. Analyzed by Cambria Steel Co.
6. Farm of D. F. Koons, Colerain Township. 2, pp. 335-336.

HELDERBERG LIMESTONES

As shown on the map the Helderberg limestones appear at the surface in two narrow bands that extend across the entire county in a direction parallel to the general trend of the mountain ridges. There are two similar narrow bands from Bedford southward but these two coalesce at Bedford and north of Raystown Branch of Juniata River form a closed loop. A few other patches of these strata are exposed in the county. The peculiar distribution of the Helderberg here is altogether due to the great longitudinal folds in this part of the State. The erosion of these folds has resulted in the development of longitudinal valleys in the more easily erodible rocks. In many places the valley floors are underlain by shales, but the Helderberg limestones are on the lower slopes of the enclosing high mountain ridges or in low secondary ridges within the narrow valleys.

The Helderberg limestones have been most extensively quarried for the manufacture of agricultural lime for local consumption and perhaps scores of small quarries have been opened throughout the county. When the iron ores of the region were mined a number of iron furnaces obtained much of their flux from the Helderberg limestones. In recent years these limestones have furnished much stone for highway construction and some quarries still are worked to supply small lime kilns.

The largest quarrying operations in the Helderberg limestones of Bedford County are in the narrow valley which includes Napier, Manns Choice, Buffalo Mills, Bard, and Hyndman. Large quarries are located near each of these small towns.

The largest active operation is that of the Enterprise Lime & Ballast Co. at the north edge of Hyndman. The Helderberg limestones form a ridge that ends at the junction of Wills and Little Wills creeks. The quarry, which is opened in the end of the ridge, is on the Baltimore & Ohio Railroad and has good shipping facilities. The quarry is an old one but for years was worked principally to obtain stone for burning. In recent years the burning of lime has been discontinued and crushed stone for railroad ballast, highway construction, and various kinds of concrete work has been the only product.

The strata are practically vertical and strike N35°E. The face is about 500 feet in width and as it is being advanced along the strike this represents an equal thickness of strata worked. The floor of the quarry is at the level of the railroad and the highest point of the face is about 125 feet. A fault at the west end of the quarry separates the limestone beds from the Oriskany sandstone. There are many different beds with varying physical characteristics and chemical composition. The beds on an average are rather thin although a few are from 3 to 4 feet thick. Some of the beds are highly fossiliferous. Near the eastern edge of the quarry a series of beds approximately 30 feet in thickness is said to have an average of 88 per cent $CaCO_3$. Next west of these (upward in the series), the $CaCO_3$ is only about 80 per cent. Three different bands have been worked for lime, all near the eastern side of the quarry in the lower beds. The last stone quarried for lime was a 15-foot thickness in the eastern third of the quarry. It was worked by a drift about 20 feet high and 75 feet long driven into the hill. The stone is said to analyze from 95 to 98 per cent $CaCO_3$. The lime made from it was sold to the paper trade.

There are a few shale partings but they are thin. Practically all the ledges meet the specifications of the State Highway Department. Several layers contain gnarly stone and there is considerable chert in the upper beds. In 1929 the capacity of the crushing plant was about 200 tons per day. An enormous tonnage of stone is readily available.

The company has furnished the following analyses made at different times. These show some of the variations in chemical composition.

Analyses of Helderberg limestones, Enterprise Lime & Ballast Co., Hyndman

	1	2	3	4	5	6	7	8
SiO_2	7.000	2.150	7.800	27.82	1.28	10.05	6.11	15.70
Al_2O_3	2.170	.750	2.550	.62	.42	1.74	3.12	3.65
Fe_2O_3	.430	.300	.200	.35	.19			
$CaCO_3$	81.650	93.697	87.830	67.40	98.10	86.91	86.59	77.33
$MgCO_3$	8.556	2.928	1.500	.57	tr.	1.20	4.15	2.91
P	.011	.008	.009					
S	.090	.040	.050					

1. Blue limestone 40 feet thick, west of high-grade, gray, fossiliferous limestone. Fleming Testing Laboratory.
2. Gray, fossiliferous limestone. Fleming Testing Laboratory.
3. Fine-grained, blue limestone east of No. 2. Fleming Testing Laboratory.
4. Screenings. C. Z. Pote, analyst.
5, 6, 7, and 8. Supplied by company.

The Peerless Lime Co. was operating a quarry just south of Hyndman in 1929 at a place where lime has long been burned. Two kilns were in operation and 3 more in ruins. The strata strike N15°E. and dip 85°NW. Two parallel quarries have been opened in this hill. The one in operation is 38 feet wide and the abandoned one 30 feet. They are separated by a band of poor stone about 30 feet thick. Still another band of good stone was worked at one time. The rock ranges in color from dark gray to bluish black and is of fairly good quality. Some shaly slabs show abundant fossils when weathered. The footwall rock of the operating quarry shows excellent fossil sun cracks. The plant is worked only during the spring and fall when the farmers want lime for their farms.

Helderberg limestones have also been quarried and burned for lime in the hillside at Cooks Mills.

In the same valley north of Hyndman, Helderberg limestones have been utilized in a number of places. Russell Mowry (Buffalo Mills, R. D.) has recently quarried stone and burned lime about 3 miles south of Bard and half a mile east. At Bard, G. B. Carpenter and R. E. Barkley have quarries where bands of Helderberg limestone 20 to 30 feet wide have been worked to obtain stone for lime and for crushed stone. The strike is almost N-S and the dip 80°E. The good stone alternates with bands of poor stone so that it would scarcely be possible to develop a large quarry, and the small operations are not very profitable. Mr. Carpenter has also pulverized some of the raw limestone for agricultural purposes.

At Buffalo Mills a small quarry has recently been worked by A. B. Robertson to obtain stone for agricultural lime. The beds strike N30°E. and dip 78°SE. Part of the stone is of fair quality but it is interbedded with some shaly layers that must be discarded. Some layers produce a strong fetid odor when struck.

C. E. Shilling works a quarry at Manns Choice, where he is burning lime. He is working a thickness of beds amounting to 47½ feet. The strike is N28°E., dip 82°NW. The plant is operated only during spring and fall to supply the local demand for farm lime. The quarry has several different grades of stone varying in hardness, color, and chemical composition. Some soft and coarsely crystalline layers are of high grade and others are hard and considerably more siliceous.

About one-fourth mile farther north Daniel Hillegas has a small quarry which he works part of the time to make agricultural lime or to pulverize raw stone for farm use. Some layers of fine quality in his quarry are gray, compact, and break with a glassy fracture.

On the north side of the Lincoln Highway at Napier a quarry in the Helderberg limestones was worked to obtain stone for the State roads. The quarry is about 125 feet wide, 250 feet long and face 80 feet high. The quarry has been driven along the strike in blue-black limestone that is thin-bedded near the surface but massive at the quarry floor. The walls on both sides are yellow, shaly limestone unfit for highway use.

On the west side of Chestnut Ridge in Napier and West St. Clair townships, and within a few miles of New Paris, seven quarries in the Helderberg were visited. A few of these will be described briefly.

The quarry of J. S. Taylor, about one mile northeast of New Paris, had just been opened when visited in August, 1929. It showed the following strata dipping 10°NW. and striking N5°E.

Section at J. S. Taylor quarry, New Paris

	Ft.	*in.*
Shaly, thinly laminated limestone	3	0
Chert		6-8
Shaly limestone	3	0
Fairly coarse-grained crystalline limestone, good quality	2	0
Gray limestone	4	0
Blue limestone	2	0
Bluish black limestone	6	0

He burns the limestone in a stone kiln and in open heap.

About 3 miles northeast of New Paris, Dorsey S. Ling has a quarry with a face about 45 feet wide. Beneath an overburden of 6 to 8 feet there is 12 feet of bluish-gray, thinly laminated limestones containing small lenses of chert 6 to 8 inches thick. Beneath these thin strata are massive, coarsely crystalline, gray limestones, the upper beds of which show abundant fossil corals. The bottom rock is dark in color. There are two steel kilns on the property.

A short distance northwest, Madison Horn has a small quarry and a lime kiln which he has operated at times for lime for his farm. The strata dip gently to the northwest. Massive, bluish-gray beds are exposed in the bottom of the quarry to the height of 3 feet. Above is 25 feet of more massive gray stone containing fossil corals. The upper portion of the opening shows thinly laminated beds in which there is considerable chert.

About 1½ miles northeast of Osterburg, G. G. Exline has a quarry in the Helderberg limestone with a face about 225 feet long and 50 feet high. The strike is N-S and dip 16°E. The quarry is being advanced down the dip. Several kinds of rock are exposed in the quarry. The best is a 15-foot series of bluish gray limestones that weather to a dove color. This has been burned for lime. There are two stone lime kilns near the quarry. Some of the exposed beds are shaly and others carry considerable black chert in bands parallel to the bedding planes, and in nodules.

Across the road to the east a quarry now abandoned was once worked by a Mr. Defenbaugh.

In Cumberland Valley south of Bedford Springs a narrow band of Helderberg limestones outcrops on the slopes of a small ridge or series of low hills much lower than Evitts Mountain to the east. In general the limestone outcrops east of the highway. The position of the outcrops makes it readily available for quarrying. In this valley, as in other regions, the quarrying of limestone for agricultural lime to be used locally on the farms is almost a thing of the past and few places have been worked in recent years.

In 1924 the only quarry in Cumberland Valley Township operated commercially was that on the farm of Amos Miller one mile east of Centerville (Cumberland Valley P. O.). It was leased and operated by A. C. Valentine. The quarry face, which is 40 feet long and 20 feet high, shows an upper knotty bed, a middle bed of massive limestone, and a shaly bottom bed, all of blue-black limestone. The beds

dip west at a low angle. The rock is burned in a single draw kiln. Other quarries in this township are those of J. D. Cessno and Peter Hite, near Centerville.

About 2½ miles south of Burning Bush, James McFarren has a small quarry and a lime kiln but they have been idle for several years. The stone is of rather poor quality and consists of some layers of good stone interbedded with shaly beds containing considerable chert.

A recent operation is that of John R. Cussins who has a quarry and lime kiln about 1½ miles east of Centerville. The quarry was worked to supply crushed stone for the new concrete road through the valley and later to obtain stone for agricultural lime. There are several different kinds of rock in the quarry, good stone, shaly layers, and beds containing chert. The strata are almost horizontal. Some gnarly layers contain great masses of fossil coral. The project may be abandoned.

East of Tussey Mountain there is a band of Helderberg limestones at one time quarried here and there. About one mile northwest of Chaneysville is a small quarry and a lime kiln operated for a short time by Ford Browning. The small hillside quarry shows stone of fair quality but greatly folded and faulted. In Black Valley there are a number of old, abandoned, farm quarries. Some of the most recently worked are near the famous old Indian spring on the farms of Mrs. Samuel Sparks and A. S. Smith.

On the south edge of Everett, A. M. McClure has a quarry and two lime kilns, now idle, although worked rather recently. A great deal of stone has been quarried at this place, mainly many years ago. The beds strike N14°E., and dip 47°SE. The quarry contains several different kinds of stone. On the whole it is of poor grade although there are some beds of fine stone. Most of it is of the gnarly type, a characteristic feature of the Helderberg limestones and best exhibited on weathered surfaces. Some layers contain much chert in lenses and thin layers. Corals and other fossils are abundant. In 1924 Mr. McClure was working a new face about 30 feet high. The original source of rock for these kilns was a quarry opened by driving a tunnel through the steeply dipping beds to a higher grade limestone. In the south end of the old open quarry a cavern has been opened about 80 feet long, 25 feet wide, and 30 feet high, apparently enlarging a natural cavern.

Just west of Everett on the north side of the river there is a quarry in the Helderberg limestone that is said to have been worked to supply local kilns for the last 100 years. The strata used are about 50 feet thick, including a 4-foot bed of very pure stone, the "calico rock" of the Frankstown, Blair County, section. The remainder of the section used was less pure but it produced a fair grade of agricultural lime. At the time of our inspection in 1921 the quarry was being worked entirely for road material and a much greater thickness was being quarried. In 1929 it was idle. It is mainly a nodular gnarly blue limestone.

Northward from Everett the only recent operation seems to be the quarry of Marshall L. Ritchey located along Pipers Run at a fork in the roads about 1½ miles west of Cypher. He has one kiln and burns stone for farm use, although some is used for whitewashing. The fine stone is used on the township roads. The beds strike N14°W., dip 11°SW. The quarry has a length of about 250 feet and a face about

30 feet high. Most of the stone is a gray limestone but there are some dark colored, somewhat shaly beds. Ripple marks are prominently shown in a shaly layer above the almost black, basal limestone. There are several small caves in the quarry which contain fine stalactites and stalagmites.

About one mile east of the Ritchey quarry is an old quarry belonging to Whitehill Brothers where lime was produced about 20 years ago.

Stevenson (2) mentions many places throughout the county where the Helderberg was formerly quarried for lime and flux but most of these quarries have long since been abandoned. In the table of analyses that follows, most of the materials reported by Stevenson obviously came from the pure strata that make up only a small portion of the entire Helderberg series.

Analyses of Helderberg limestone in Bedford County

	1	2a	2b	2c	2d	3	4	5
$CaCO_3$	98.178	96.61	85.81	94.28	91.95	89.635	92.875	96.592
$MgCO_3$	1.854	1.44	2.82	3.27	1.86	1.876	1.891	2.459
SiO_2	.230	1.28	7.56	1.54	4.24	6.880	4.810	.930
Al_2O_3 / Fe_2O_3	.114	.34	3.22	.64	2.50	.610	.370	.240
S	.020	.06	.32	.04	.07	.022	.030	.019
P	.007	.010	.010	.009	.011	.005	.005	.008

	6	7	8a	8b	9	10	11
$CaCO_3$	94.107	90.660	82.60 to 92.90	87.19	91.071	84.500	96.592
$MgCO_3$	2.444	2.542	1.27 to 10.40	5.19	2.543	10.019	2.459
SiO_2	2.750	6.250	2.60 to 7.06	4.62	5.590	4.820	.930
Al_2O_3 / Fe_2O_3	.240	.822	1.20 to 3.90	2.45	.440	.713	.240
S	.036	.056	.04 to .30	.11	.068	.062	.019
P	.010	.008	.006 to .032	.013	.006	.012	.008

1. W. Devore's quarry south of Hyndman (T2, p. 97).
2. a, b, c, and d—Enterprise Lime & Ballast Co. quarry, Hyndman. Analyses by Cambria Steel Co.
3. Wilmetto Limestone Co. quarry just north of Wills Creek Station, (2, p. 106).
4. Shoemaker quarry immediately north of Manns Choice. (2, p. 112).
5. A. Stuckey's quarry, Napier Township, (2, p. 115).
6. L. Geisler's quarry, a short distance east of St. Clairsville (2, p. 129).
7. Hull's quarry, King Township (2, p. 132).
8. R. N. Oppenheimer farm, 6 miles north of Bedford; 5 samples, 8a, range, 8b average.
9. Stapleton's quarry, ½ mile south of Juniata River, southwest of Everett (2, p. 191).
10. J. Piper's quarry, on Piper's Run, Hopewell Township (2, p. 196) Analysis by Cambria Steel Co.
11. Kemble Coal & Iron Co.'s quarry near Cove Station, Black Valley, within a few rods of the Huntingdon County line. (2, p. 200)

UPPER DEVONIAN AND MISSISSIPPIAN LIMESTONES

There are some limestones or calcareous shales in the Upper Devonian strata of Bedford County. They are of little value because they consist of thin layers interbedded with shales and in this county they are of even less importance than they might otherwise be because of the great abundance of better materials in the Cambro-Ordovician and Helderberg series.

It is probable that some Pennsylvanian or Mississippian limestones may be developed along the extreme western portions of Bedford County, although no such occurrences are known to the writer. Opportunity was not offered to make any detailed investigations in that section.

Practically all the outcropping Carboniferous strata of Bedford County are confined to the Broad Top region. A study of the coals of that region has been made by James H. Gardner (4) in which a detailed columnar section to the base of the Pottsville is shown. It includes a 3-foot bed of fine-grained bluish limestone in the Monongahela group, two locally developed limestones in the Allegheny group, probably representing the Freeport limestones of other districts. From all information available it seems that the Coal Measures limestones of the region are of little or no economic importance.

The Mauch Chunk red shale that is exposed as a band up to 3 miles wide surrounding Broad Top and extending northward in Little Trough Creek valley about 12 miles and southward a greater distance in the west part of Fulton County contains considerable limestone interbedded with shales. Most of the limestone is red and quite impure, containing up to 40 per cent of siliceous material, yet it has been utilized for agricultural lime locally. Some gray layers are purer. These limestones of the Mauch Chunk series seem to represent the Greenbrier limestone of the region on the west.

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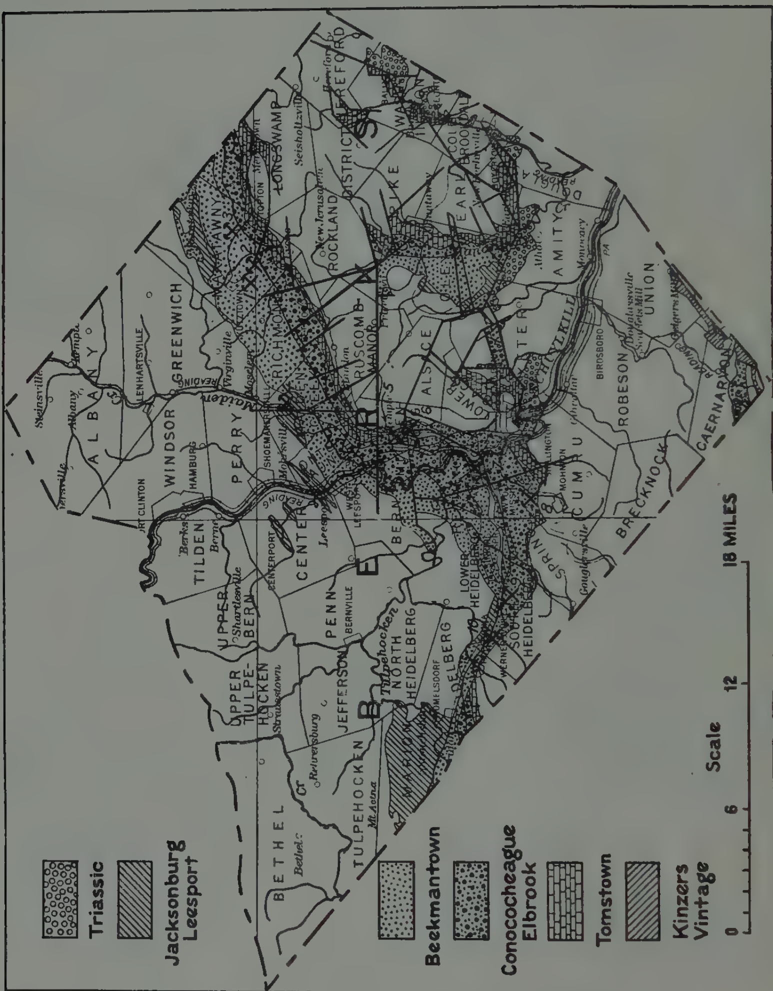

Fig. 4. Limestone areas in Berks County.

1. Kutztown Crushed Stone Co.
2. Martin Koller
3. Topton Furnace quarry
4. Allentown Portland Cement Co.
5. Reading Quarry Co.
6. Berks Products Corp. (Berks Cast Stone Co.)
7. Robert L. Kline
8. Berks Products Corp. (Fehr & O'Rourke Stone Co.)
9. Wernersville Lime and Stone Co.
10. A. V. Gaul

BERKS COUNTY

Berks County is well supplied with limestones of different kinds so distributed near the centers of population that they are readily accessible for use. The principal area lies within the Great Valley which cuts across the central part of the county and in which nearly all the towns of importance are located with the exception of Hamburg, Boyertown, and Birdsboro. Oley Valley also contains a large area of limestone and there are detached smaller areas such as the one 2 miles east of Seisholtzville, in the vicinity of Hereford, north of Dale, between Clayton and Churchville, near Barto, Bechtelsville, near New Berlinville and along Manatawny Creek east of Pikesville. There is an extension of the Lancaster County limestones in the vicinity of Morgantown in the extreme southern end of the county. In addition there are prolongations from the Great Valley region in narrow valleys such as the one extending from Reading almost to Boyertown and another along Little Lehigh Creek south of Longswamp.

The limestones of Berks County of economic importance all belong to the Cambrian and Ordovician periods. It is worth while mentioning, however, that the Franklin formation of pre-Cambrian age is present in the vicinity of Seisholtzville and that some limestone conglomerates of Triassic age are locally developed south and east of Reading.

PRE-CAMBRIAN LIMESTONES

In a report on graphite in Pennsylvania, the writer has described an occurrence of Franklin limestone in Berks County as follows (4, pp. 113-114):

"Graphite occurs in gneiss and Franklin limestone at the Bittenbender Iron Mine, one-half mile northeast of Seisholtzville. The mine has furnished a large amount of high-grade magnetite ore but has not been operated for several years. No graphite has ever been mined at this place but its abundant and varied occurrence warrants a brief description. It furnishes another illustration of the intimate connection existing between the Franklin limestone and the graphitic gneiss of Pennsylvania.

"No observations could be made of the various graphite-bearing rocks in place and the following information was obtained through a study of the rocks on the waste heaps near the mine opening.

"Many specimens of white crystalline limestone with flakes of graphite ¼ inch in diameter, irregularly disseminated, were seen on these waste heaps. The flakes show no regularity of arrangement. Some of the limestones seem to have been altered to silicate rocks with segregations of augite, graphite, and an asbestiform mineral.

"Other rocks consist of dark red garnet, hornblende, augite, and graphite. Specimens of massive magnetite were observed in which there were occasional partings of graphite. Some of the rocks consist of massive hornblende, augite, some hypersthene, and graphite flakes. Gneiss such as occurs in other graphite areas is also present in which the mass of the rock is composed of plagioclase, quartz, augite,

and flakes of graphite 1/8 inch in diameter. Pegmatites composed of orthoclase, quartz and large graphite flakes are represented by occasional specimens.

"In no other place in the State is there such a variety of graphite rocks so that it is especially unfortunate that their relations are not known. It is improbable that any of them could ever be profitably worked for graphite."

CAMBRO-ORDOVICIAN LIMESTONES

The Cambrian and Ordovician limestones of the Great Valley and its off-shoots lie within the counties of Northampton, Lehigh, Berks, Lebanon, Dauphin, Cumberland, and Franklin.

The limestones of Northampton, Lehigh, and Berks counties form a continuous band from four to eight miles wide occupying the central portions of these counties and trending from northeast to southwest. In addition to the main body, there are in each of the three counties some partially and wholly detached smaller areas resulting from folding and faulting of the strata and subsequent erosion. As a consequence of similar complexities of structure there are some small outliers of both older and younger non-calcareous rocks within the limestone areas.

The limestones of this belt are bordered on the south and southeast by the higher ridges known variously as South Mountain, Lehigh Mountain, or Durham and Reading Hills. These ridges composed of the resistant Cambrian sandstones and quartzites and pre-Cambrian gneisses, rise to a height of 900 to 1,100 feet above sea level. The limestones in the adjacent valley have an elevation of 200 to 500 feet. On the north and northwest the limestones are in contact with the younger shales and slates of the Martinsburg (Hudson River) formation. These are more resistant to erosion than the limestones and therefore the summits of the slate hills are considerably higher, rising to elevations of more than 800 feet in many places.

The limestones of this belt have been divided into several formations as shown in the following table, although the area has not yet been completely mapped.

Classification of the Cambro-Ordovician limestones of Northampton, Lehigh and Berks counties

	Feet
Ordovician	
Martinsburg shales and slates overlying the limestones.	
Canadian	
Jacksonburg (Trenton, Leesport) low-magnesian argillaceous limestones extensively used in manufacture of Portland cement	250-600
Beekmantown limestone, normally high in magnesium carbonate	1,000±
Conococheague (Allentown) dolomitic limestone	1,500±
Cambrian	
Tomstown dolomitic limestone	1,000±
Hardyston sandstone and quartzite underlying the limestones	

In general it is possible to differentiate the limestone formations, although there are some places where this cannot be done with certainty. All of the limestones were deposited in shallow water and ex-

hibit the characteristics of such deposition,—ripple or wave marks, sun or mud cracks, rain drop prints, breccia and conglomerates, oolite, and frequent and rapid changes in physical and chemical composition both laterally and horizontally. They have also all undergone much metamorphism which probably destroyed many of the fossils, although it is not believed that these limestones ever were rich in organic remains except in restricted localities. Recrystallization of the carbonates is common and considerable sericite is present along the bedding planes. All the limestones contain numerous joints and calcite and quartz veins.

Tomstown group. The Tomstown formation contains considerable interbedded shaly material that has a tendency to weather quickly so that good outcrops are seldom found. It also contains some massive-bedded, compact layers normally dark blue in color. The formation is everywhere high in magnesia carbonate and in many places quite siliceous. No fossils have been found in the formation. The Tomstown outcrops along the lower slope of the quartzite and gneiss hills except where faulting has placed other formations in this position. The thickness is approximately 1,000 feet. The Tomstown dolomite has been quarried for lime, flux, crushed stone and in a few places for building purposes.

Conococheague formation. The Conococheague (locally designated Allentown) formation is the thickest and most prominent of this series of limestones. It is normally present near the center of the limestone valley although, due to folding and faulting, it may be found in other places. It can usually be recognized by the abundance of the fossil *Cryptozoon proliferum,* a form of calcareous algae that was graphically described by Lesley, former State Geologist, who did not recognize its true character, in the following sentence: "A very strange peculiar and entirely mysterious feature of some beds is a structure resembling a mass of clam shells closely packed together with their rounded sides uppermost." On the edges of the beds, they appear as a series of thin layers in symmetrical waves that vary from half an inch to more than a foot in width. On the upper surface they appear as small knobs or bumps from one-half to one inch in height.

The Conococheague limestones are everywhere high in magnesium carbonate, although there is considerable variation. Deep weathering gives a banded appearance to interbedded strata with different percentages of magnesium carbonate because the more highly dolomitic beds turn whiter than others. This is generally an excellent criterion for recognizing the formation, as the other formations of the region do not show this phenomenon well. Some layers are highly siliceous and in several localities there are a few thin interbedded sandstone layers. Shaly beds are present but not common. The best figures that have thus far been secured for the thickness of the Conococheague limestone approximate 1,500 feet.

The Conococheague has been quarried extensively for lime and crushed stone, less extensively for flux, and in a few places for building material.

Beekmantown formation. The Beekmantown formation is mainly confined to the northern or northwestern part of the limestone belt.

In places several species of molluscan fossils are present although, as a whole, organic remains are very scarce. The individual limestone beds are more heterogeneous than those of the underlying formations. This is not especially noticeable on fresh surfaces but is pronounced on weathered portions, producing an irregularly mottled appearance. Unlike the Tomstown and Conococheague formations, the Beekmantown contains occasional beds of low magnesian limestone that are suitable for the manufacture of Portland cement. No place is known, however, where the thickness of these layers is great enough for a quarry to be opened in them alone; consequently in quarrying it is necessary to sort the material carefully by hand and use the high magnesian stones for other purposes if material for cement is sought in the Beekmantown strata. The formation has an approximate thickness of 1,000 feet.

Jacksonburg formation. The uppermost limestone formation of this area is the Jacksonburg, more commonly known as the Cement Rock formation, because it has furnished such a large quantity of stone for making Portland cement. The formation has not been recognized throughout the entire region, thus indicating an unusual and somewhat local type of deposit.

The Jacksonburg overlies the Beekmantown limestone and is overlain by the Martinsburg shales and slates.

The characteristics of the Jacksonburg limestone are discussed on a later page describing the Evansville area.

Martinsburg formation. A few lenses of limestone are present within the basal Martinsburg shales and have been quarried for lime in several places on a small scale. They are of minor importance.

Structure. The structure of all the limestone strata of Berks County is very complex. Folding and faulting have so greatly disturbed the strata that rarely can one find any considerable area in which the beds are even approximately horizontal. Simple folds and overturned folds, normal faults and thrust faults of minor and major degree have been observed in scores of places. Were it not for the surface soils that so generally conceal the strata our detailed maps would show many more faults and axes of folds than they now do. Correlation of beds and determination of exact thickness are impossible in most places. Both the folds and faults have a general trend from east to west or northeast to southwest but there are many transverse to these lines.

Joints and veins of calcite and quartz are common in all the limestone formations of the region and consequently good structural material is uncommon.

QUARRY ECONOMICS

Not uncommonly bluffs from 20 to 160 feet high rise above the streams. Railroads follow nearly all the major streams and some of the minor ones. The conditions favor limestone quarrying as a quarry face with good drainage can easily be developed and transportation facilities are close at hand. The overburden of residual clay or rotten limestone is seldom thick. It perhaps averages about 4 feet. Solution pits or pockets in the rock surface are common and are

always filled with clay. Deep pits are a serious obstacle in working a quarry. Fissures filled with clay are also encountered in many quarries. Cavities or small caves containing cave onyx are not uncommon but in no place in the district have these cave deposits been of economic importance. In general the solution cavities of all kinds are most numerous where folding and the consequent shattering of the rocks have been most intense.

For additional information concerning the characteristics and uses of the limestones occurring in Berks County, the reader is referred to the chapters on Lehigh and Northampton counties.

The Cambro-Ordovician limestones of Berks County at an early period were worked for building stones for local use, for flux in the various iron furnaces throughout the county, and for lime. At present, scarcely any use is being made of them except for crushed stone, for which they are well fitted. The one cement plant in the county at Evansville uses the Jacksonburg limestones that are scarcely serviceable for any other purpose.

It is not advisable to attempt to describe all the limestone quarries of the county; attention will largely be confined to those now in operation. It is probable that there are over 200 old quarries in the county, most of which are small and were worked only for local use.

Kutztown-Topton Area. In the vicinity of Kutztown and Topton, a number of quarries have been worked in years gone by to supply stone for agricultural lime and furnace flux. With no iron furnaces now active in the region and agricultural lime seldom produced locally, all of these quarries are closed. The number of attractive old stone houses scattered about, all built of local limestones, make it evident that many of the quarries were worked solely or in part for building stones.

At present only 2 limestone quarries are in operation in the area. Both are located a short distance south of Kutztown. The Kutztown Crushed Stone Co. is working a quarry about half a mile southeast of the Kutztown State Teachers College. In this ridge there are a number of old openings and abandoned lime kilns. The beds are fairly massive and are varied in composition, ranging from a dense, dark blue dolomite to a dark gray, low-magnesian limestone. These are interbedded so that it would be difficult to quarry the different varieties separately. The stone appears to belong to the Beekmantown formation. The beds strike N.65°E. and dip 20°SE. The quarry is about 400 feet long on the strike, 175 feet wide and has a face about 60 feet high. The stripping is light, 3 to 4 feet on an average. The plant can produce 500 to 600 tons of crushed stone daily. Nearly all goes to the State and Township roads. Old lime kilns show the former use for the product of this quarry.

Martin Koller is working a quarry for crushed stone about three-fourths mile southeast of the plant just described. He has a quarry about 350 feet long, 100 feet wide and with a face about 35 feet in height. The beds are gently rolling but averages practically horizontal. The strata are massive, 1 to 2 feet thick, and with the exception of one dark-colored, high-calcium bed are all highly magnesian. The overburden of clay is heavy and in places it extends downward

into cracks. The quarry and crushing plant can produce 150 tons of crushed stone daily.

The old Topton Furnace quarry at Hinterleiter about 2½ miles northwest of Topton is now idle but it was long worked to supply stone for the Topton iron furnace. The quarry is a large one with a high face and has furnished a very large amount of stone. The beds show variations in dip and strike but the dips are everywhere gentle. Most of the beds are low in magnesia. There are, however, several high magnesian strata. One of these on the west wall is of interest because it shows abundant gash veins of calcite and dolomite, whereas the overlying and underlying low magnesian beds are practically free of vein matter.

A composite analysis of stone from this quarry is as follows: SiO_2 — 4.08; $Al_2O_3 + Fe_2O_3$ — 2.14; $CaCO_3$ — 90.44; $MgCO_3$ — 3.66.

Moselem Springs—Kirbyville Area. In the vicinity of Moselem Springs and Kirbyville there are about 20 old quarries, all of which seem to have been operated in Beekmantown limestone. They are all idle now and most have probably not been worked during the past 40 years or longer. Near almost every quarry is an old lime kiln. From the number of stone houses in this section, it appears that the quarries also were worked for building stone. The stone exposed shows interbedded dolomite and low magnesian limestones. The largest of these quarries are along Moselem Creek from a mile to a mile and a half north of Moselem Springs.

Evansville Area. The Evansville area is of special interest because there is located the only Portland cement plant in Berks County. The Allentown Portland Cement Co. has been manufacturing Portland cement there since 1910. Previously Portland cement was made by the Vindex Portland Cement Co. about 1½ miles to the southeast. This plant was abandoned because of the poor quality of the stone.

The Allentown Portland Cement Co. is working the argillaceous limestone of the Jacksonburg formation, the same type of stone used by all the cement plants of the Lehigh Valley. It overlies the Beekmantown limestone which contains high and low magnesian limestones and is in turn overlain by the Martinsburg shales and slates. In the vicinity of Evansville, there is a detached block of the Jacksonburg where the plant was built. The rock resembles a black shale or slate and yet it analyzes about 74 per cent $CaCO_3$. The beds are considerably crumpled but have a general strike of N.44°E. and a dip of 22°SE. The quarry is roughly about 1500 feet long, 700 feet wide, and 120 feet deep.

As is true throughout the Lehigh District, the cement rock at Evansville varies considerably in composition. Some fresh samples contain less than 60 per cent $CaCO_3$ and some of the surficial weathered materials, where solution has been active, contain practically no lime. Occasional specimens can be selected in which more than 90 per cent $CaCO_3$ is present, with several feet of rock here and there containing more than 80 per cent $CaCO_3$. In portions of the quarry and also in some of the drill holes the distribution of the various grades of stone appears to be extremely irregular.

Several explanations are offered to account for these irregularities but in advance of the close drilling for blasting it is usually impossible

to decide which is the correct explanation. In some places the rock has been thrown into close folds or displaced by faulting which brought poor stone into the place where, normally, high grade stone should be found. In other places, fissures or shattered zones have admitted surface water to depths where the rock commonly is unaffected by the action of surface water. The effect of these waters is to remove considerable portions of the $CaCO_3$ and make the stone much poorer. Elsewhere it appears that there were rather sudden and decided changes in composition of the deposit in short distances as it was laid down originally in the shallow ocean waters. Notwithstanding these variations there are some well defined bands of fairly uniform grade that can be traced across the property.

The following composite analyses of the material obtained in some prospecting holes show some of the variations in chemical composition. Analyses 1, 2 and 3 are from 50-foot holes, 4 a 125-foot hole and 5, 6 and 7 150-foot holes.

Analyses of limestone at Evansville

	1	2	3	4	5	6	7
SiO_2	19.04	18.70	16.92	15.04	16.08	15.88	16.64
Al_2O_3 + Fe_2O_3	6.32	6.38	7.02	5.64	6.08	6.04	6.24
CaO	37.99	38.60	39.51	41.40	40.44	40.48	40.10
MgO	2.60	2.24	2.37	2.04	2.40	2.14	2.33
Loss	33.26	33.86	33.85	34.04	34.54	35.24	34.26
Total	99.21	99.77	99.67	98.16	99.54	99.78	99.57
$CaCO_3$	67.84	68.93	70.55	73.93	72.21	72.29	71.61
$MgCO_3$	4.70	5.46	4.98	4.28	5.04	4.49	4.89

The Allentown Portland Cement Co. uses the dry process of manufacture. It has 4 rotary kilns, 8 feet in diameter and 120 feet long. Its annual output is 1,400,000 barrels.

Maiden Creek Station Area. Along the Reading Railroad about three-fourths mile northeast of Maiden Creek Station, considerable quarrying has been done in Beekmantown limestone, which here shows numerous fossils on the weathered surfaces. Some high grade limestones here are interbedded with highly magnesian beds. The Allentown Portland Cement Co. obtained some good limestone here, but abandoned the quarry because of the magnesian stone. Lime was once burned here. There are several openings in close proximity.

A short distance north of Willow Creek and about 1¼ miles south of Maiden Creek Station is an old quarry in the Conococheague formation. Some layers contain the algal fossil, *Cryptozoon proliferum.* The rock is gray to grayish blue, and fairly high in magnesia. The beds are massive. They dip about 25°N. The stone from here was once burned. It would produce a good quality crushed stone.

Leesport-Rickenbach Area. Several quarries have been worked on both sides of Schuylkill River between Leesport and Rickenbach. One of these located almost due west of Rickenbach station on the Reading Railroad has been worked on the line of strike for fully 400 feet. The strike here is N.34°E. and the beds dip 66°NW. The portion which has been worked out has a general width of 50 feet in the

east end of the opening and narrows down to about 20 feet in the middle portion of the quarry. The thickness of the beds exposed is about 40 feet and they are mainly gray to grayish blue, somewhat siliceous limestones. Some of the beds, especially those that have been badly leached, have been infiltrated by clay on the south hillside while others appear to be quite durable and have withstood weathering exceptionally well. A 6-foot, massive, blue, siliceous stone forms the underlying bed of the quarry and shows a pitted surface.

At a small opening with a 25-foot face in the hillside about half a mile north of Rickenbach station, the strata have the same general dip and strike as noted in the previously described quarry.

About half a mile south of West Leesport is a quarry connected by spur to the Reading Railroad. Many large blocks of burned lime were observed, exceptionally white in color. A battery of six lime kilns indicates the use of the stone. The quarry has been worked in two benches, the lower one having 10-foot and the upper a 20-foot face. The length of the face is about 300 feet. Because of the general contortion of the beds and the obscure bedding planes, it is difficult to obtain general dip and strike. At the extreme north end of the quarry, the beds show an anticlinal axis and pitch steeply to the north. An analysis of the stone shows: Loss on ignition—44.13; SiO_2—1.60; $Fe_2O_3+Al_2O_3$—.70; CaO—48.95; MgO—4.18.

There are two old quarries about one-third mile south of West Leesport and another one almost opposite on the east side of Schuylkill River.

Temple—North Reading Area. Of three large quarries all close together a short distance southwest of South Temple, only one is now in operation. The most northerly one is located just west of the Reading Railroad (Schuylkill Division) about one-third mile south of Temple Station, and was long worked by the Reading Quarry Co. The opening is a large one, and was probably operated for a great many years. The quarry face is about 70 feet high. It is now idle and much of the plant equipment has been removed. There are 7 kilns. It is said that all the stone from here was burned for lime. The stone is all highly magnesian. In color the stone is mainly gray, but some is dark blue. The beds are thick and have a fairly uniform strike N.73°E. and dip 18°SE. Stylolites are extremely prominent along the bedding planes. Oolites and limestone conglomerates were also noted. The rock is part of the Conococheague formation.

A short distance to the south along the new highway is the extensive quarry of the Berks Cast Stone Co., a subsidiary of the Berks Products Corporation. The latter organization represents a consolidation of practically all the producers of crushed stone in the Reading district. Since this consolidation, most of the quarries have been closed and the work concentrated in the quarry of the Berks Cast Stone Co. for the supply of the north part of Reading, and the old Fehr & O'Rourke Stone Company's quarry at Shillington to supply the needed stone for the south and west part of Reading. The quarry of the G. W. Focht Stone Co. just west of the Berks Cast Stone Company's quarry and the Mays Bros. Inc. quarries at West Reading and Glenside have been closed.

The quarry of the Berks Cast Stone Co. is roughly 400 feet long, 200 feet wide and the face is 80 feet high. The beds are fairly massive

and strike N.66°E. and dip 14°SE. The stone varies in chemical composition and on weathering some beds become much whiter than others, producing a banded appearance, characteristic of the Conococheague formation. Most of the stone is less highly magnesian than most of the limestones of this formation. In color the stone is light gray to bluish gray. In places the stone contains much vein matter. The plant is a well equipped one in every respect and has a capacity of 80 tons of crushed stone per hour. It is planned to increase this to 100 tons. Some of the fines from the screens is sold for sand. An amiesite plant located near by takes some of the stone. A drier is installed to dry the product before being mixed with the asphalt. A dust collector attached to the drier removes some very fine material which is sold for agricultural use. An analysis furnished by the company shows 68.73 per cent $CaCO_3$, 10.60 $MgCO_3$, and 19.19 acid insoluble matter.

The idle quarry of the G. W. Focht Co. located near by contained stone similar to that in the quarry just described.

The abandoned quarry at Glenside is in the Beekmantown formation. Most of the stone is low in magnesia, although there are some highly dolomitic interbedded strata.

Reading Area. Within the City of Reading a number of quarries in the Beekmantown limestone at one time or another have been worked for limestone. Most of these are on the west bank of Schuylkill River. Some of these are large and have furnished satisfactory stone for building construction, for lime, and more recently for crushed stone. Due partly to the proximity of residences and partly to the merger of nearly all the quarry companies in the vicinity of Reading, all except one of these quarries has now been closed and it is doubtful whether most of them will be reopened.

Robert L. Kline is working a small quarry on Spruce St., West Reading, between 4th and 5th Avenues. The rock is mainly a hard, dark-colored, magnesian variety much of which has been shattered and contains numerous gash veins of calcite and dolomite. Layers of interbedded, gray, compact marble on weathering become light pink. The beds dip to the south at angles ranging from 20° to 40°. The quarry is being advanced westward along the strike. The opening is 50 to 60 feet wide and the face about 20 feet high. The product is crushed stone.

Shillington Area. The Shillington plant of the Berks Products Corporation was formerly the property of the Fehr & O'Rourke Stone Co. It is located just west of Wyomissing Creek to the northwest of Shillington. This is a large quarry in the Conococheague formation. The stone varies in color from gray to dark blue, and in composition from dolomite to low magnesian limestone. The beds are mainly massive; in south part of quarry they are almost flat but in north have a gentle northerly dip. Calcite veins are numerous in certain parts of the large quarry. There are also several faults, and slickensided surfaces are common. The quarry is roughly 700 feet long, 350 feet wide, and has a face 65 feet high at the highest point. The overburden is from 3 to 6 feet except in one place where a large clay filled pocket extends down about 30 feet. The daily capacity of the plant is about 1,000 tons of crushed stone. An

analysis furnished by the company shows 64.08 per cent $CaCO_3$, 20.33 per cent $MgCO_3$ and 13.87 per cent acid insoluble matter.

Areas west of Reading. West from Reading, one passes through a limestone valley where scores of quarries have once been operated, mainly to obtain stone for burning to lime and for building purposes. Practically all of these openings have long been abandoned and the lime kilns are in ruins. Only a few are regarded as worthy of description. D'Invilliers (see bibliography at close of chapter) describes 29 quarries in this section and shows their location on a map contained in the Atlas.

One of these quarries is about one mile west of Sinking Spring along the south side of the Harrisburg pike just west of the road leading north to the Green Valley Country Club. The opening is about 125 feet long and over 20 feet high. Two pits have been worked along the line of strike, the easterly pit having been better developed. The rocks for the most part weather a distinct grayish-blue and seem to be fairly high in magnesia.

An old lime kiln and a somewhat irregular pit close to Little Cacoosing Creek about 1½ miles northwest of Sinking Spring indicate spasmodic operations in the past. It is about 100 yards west of the lane leading north from the Harrisburg pike and at the base of a 40-foot hill. Only a few beds are exposed to a height of about 10 feet but the bluish-black color of the stone gave field evidence of a fairly low grade magnesian stone. The analysis follows:

Analysis of limestone 1½ miles northwest of Sinking Spring

SiO_2	.59
$Fe_2O_3 + Al_2O_3$	.49
CaO	54.86
MgO	.61
Loss on ignition	48.73
Total	105.28
$CaCO_3$	97.98
$MgCO_3$	1.28

Another quarry is 100 yards farther north in the same hill. It is on the south bank of Little Cacoosing Creek and has been driven approximately at right angles to the wagon road. A massive 3½-foot bed of limestone forms the basal member and is overlain by a massive blue-gray bed 10 feet thick. The dip of these beds is to the south and would carry them under the quarry described above. The stone is probably as high grade as that in the other quarry, except that there are some rather siliceous lenses in the massive beds.

About half a mile up Little Cacoosing Creek from the hamlet of Cacoosing is a quarry that apparently has been extensively worked. Because of the large number of cut blocks, it appears to have been worked for foundation and building stone. The entire quarry face, which is one of the best seen in the general area, is about 125 feet long and could be worked farther southwest along the hill. It has a height of 30 feet. Most of the stone is bluish-gray and is massively bedded. One massive ledge is about 15 feet thick; above it is a

smaller bed which contains some clay seams. A bed 18 inches thick weathering to gray follows, then blue stone forms the remainder of the section, which is capped by about 3 feet of overburden. The rocks of the quarry dip gently southwest. The analysis of the samples from this quarry follows:

Loss on ignition, 42.06; SiO_2, 5.40; $Fe_2O_3 + Al_2O_3$, 1.52; CaO, 46.62; MgO, 4.68.

The Wernersville Lime & Stone Co. is working a quarry just southeast of Wernersville for crushed stone. Formerly lime was burned here. The stone is mainly dark gray or blue, fairly high in magnesia, and hard. There are a few bands of light gray to pinkish, fine grained marble in the quarry. These are low in magnesia and present a striking contrast to the other stone. The stone has been much shattered by faulting and compression, and veins of calcite are abundant. A number of faults with well-defined slickensided surfaces can be observed. The quarry face is about 65 feet high. The plant produces about 25,000 tons of crushed stone yearly.

A. V. Gaul operates a quarry for crushed stone along the south side of the highway about midway between Wernersville and Robesonia. Lime was formerly burned here. The stone is mainly thin-bedded, dark-colored, and low in magnesia. Loose blocks of white to pinkish, dense marble were observed in the quarry but not seen in place. The quarry face is about 65 feet high. The beds strike N.23°W. and dip 55°SW. The clay overburden is fairly heavy and some joints in the stone are filled with clay.

East, west and south of Stouchsburg there are a number of abandoned quarries. Nearly all of them show interbedded dolomite and low magnesian stone; in most cases the varieties are not thick enough to permit one type to be worked separately. Practically all were worked for stone for making agricultural lime. A quarry close to Tulpehocken Creek about one mile northwest of Womelsdorf has been worked for roadstone. It contains hard, brittle, black, siliceous limestone.

Limestone Areas south of the Great Valley. As mentioned above, there are several smaller, detached limestone areas south of the Great Valley. These are almost entirely confined to Hereford, Washington, Pike, Colebrookdale, Douglass, Amity, Oley, and Exeter townships. Oley Township contains the largest area; in fact, the surface rocks in this township are mainly limestone.

In these areas, there has been little quarrying of limestone in recent years. When E. V. d'Invilliers studied the region for the Second Geological Survey in 1882, many of the quarries were then being worked. In his report (see bibliography at close of chapter), he devotes 38 pages (pp. 142-180) to the description of these quarries and gives many analyses. He also describes a number of quarries in the vicinity of Reading (pp. 180-197). It is not advisable to reprint here the details given by d'Invilliers but the analyses which he gives are all included in the table at the close of this chapter.

There are 6 quarries near the Berks County line about 2 miles east of Seisholtzville. All are said to contain dolomitic limestones. The stone was burned for local farm use.

In Dale Forge Valley, which lies partly in Hereford and partly in Washington Township, four quarries have been described. Several different kinds of stone are present, most of which are dolomitic. The stone was burned for lime.

Some poor limestone has been worked near Hereford. One-fourth mile north of Clayton, magnesian limestone was dug and burned. About one-eighth mile southwest of Clayton some siliceous magnesian limestones were quarried and burned. Half a mile north-northwest of Bechtelsville magnesian limestones (2, p. 150) varying "from a gray cherty limestone through dove color to a hard massive blue stone" were quarried for lime. Half a mile southwest of Bechtelsville a quarry (2, p. 151) "exposes about 30 feet of blue and dove-colored limestone interstratified with inches of limestone shale."

One-fourth mile northeast of Greshville is a large quarry (2, p. 153) "with 60 to 80 feet of good blue and white stone exposed." As much as 75,000 bushels of lime annually was produced here. There are two quarries used for lime about one-fourth mile west of Greshville. There were two quarries in the southeast corner of Earl Township 1¼ miles east of Earlville. A good grade of dolomite was quarried one-fourth mile north of Earlville and similar but more siliceous stone two-thirds mile north of the same village.

In Oley Valley there are many old limestone quarries. In general, the eastern part of the valley is floored with magnesian limestones of the Conococheague formation and the western half is underlain by Beekmantown limestones consisting of many high-calcium beds interbedded with some magnesian beds. For this reason Oley Valley has a rather great variety of limestones. These old quarries once supplied the farmers with stone for lime and now are capable of producing an excellent quality of crushed stone.

The following analyses are from Second Geological Survey Report D3, vol. 2 and were made by A. S. McCreath, except 41a and 41b:

Analyses of Cambro-Ordovician limestones of Berks County

	1	2	3	4	5	6	7	8
$CaCO_3$	52.857	53.839	54.714	26.053	51.839	19.821	87.267	55.053
$MgCO_3$	42.779	42.042	43.380	19.077	40.523	14.529	8.324	38.094
SiO_2	3.890	3.410	1.220	50.610	7.170	64.370	3.480	6.280
Al_2O_3 / Fe_2O_3	.650	.810	.990	2.330	.860	.810	.810	.730
P	.004	.008	.003	---------	.005	---------	.006	---------

	9	10	11	12	13	14	15	16
$CaCO_3$	54.643	63.928	53.392	52.357	54.267	91.964	95.125	59.875
$MgCO_3$	41.598	12.884	41.848	40.363	42.611	2.337	1.036	36.024
SiO_2	3.400	20.110	3.600	6.420	2.470	5.910	3.680	2.760
Al_2O_3 / Fe_2O_3	.750	1.730	1.090	.550	.730	.180	.210	1.660
P	---------	---------	---------	.006	---------	---------	---------	.009

	17	18	19	20	21	22	23	24
$CaCO_3$	66.535	79.107	87.642	92.214	63.107	96.178	88.857	90.357
$MgCO_3$	21.645	14.227	9.837	4.986	27.402	2.176	3.783	2.800
SiO_2	9.630	5.690	2.240	2.750	8.210	1.750	6.800	6.640
Al_2O_3 / Fe_2O_3	1.940	.520	.570	.420	1.450	.290	.810	.310
P	---------	.003	---------	---------	---------	---------	---------	---------

	25	26	27	28	29	30	31	32
$CaCO_3$	71.178	96.667	95.500	97.321	51.303	92.142	95.575	90.214
$MgCO_3$	23.263	2.081	2.724	1.496	32.713	1.832	1.535	6.420
SiO_2	4.770	1.010	1.940	1.320	15.220	5.830	2.950	3.500
Al_2O_3 } Fe_2O_3	1.080	.350	.230	.210	1.060	.560	.280	.210
P	.005	--------	--------	--------	--------	--------	--------	--------

	33	34	35	36	37	38	39	40
$CaCO_3$	81.286	89.914	60.089	80.160	87.910	86.889	67.821	51.303
$MgCO_3$	10.412	2.714	38.185	9.459	7.340	5.728	24.025	37.557
SiO_2	7.830	7.890	1.290	9.100	4.590	7.240	7.050	9.130
Al_2O_3 } Fe_2O_3	.870	.520	.230	.980	.370	.470	1.340	1.960
P	--------	--------	--------	--------	--------	--------	.009	--------

	41a	41b						
$CaCO_3$	52.67	47.316						
$MgCO_3$	44.64	40.509						
SiO_2	1.42	9.900						
Al_2O_3 } Fe_2O_3	1.27	2.275						

1. Quarry of Jonas Shaub, 2 miles east of Seisholtzville near Lehigh County line, Berks County (2, p. 144).
2. Schall quarry ¼ mile north of Dale (2, pp. 146-147).
3. Clemmer quarry, ¼ mile north of Clayton (2, p. 149).
4. Diehl quarry, ⅛ mile below Clayton (2, p. 149).
5. Oberholtzer quarry, ½ mile northeast of Bechtelsville (2, p. 151).
6. Miller quarry, ½ mile southwest of Bechtelsville (2, p. 151).
7. Levi Gresh quarry, ¼ mile northwest of Greshville (2, p. 154).
8. Dandheiser quarry, ¼ mile west of Greshville (2, p. 155).
9. Keely quarry, ¼ mile west of Greshville (2, p. 155).
10. Rapp quarry, 1-¼ miles east of Earlville (2, p. 156).
11. Quarry ¼ mile north of Earlville (2, p. 160).
12. Quarry on Powder Mill Creek (Trout Run) 2/3 mile north of Earlville (2, p. 161).
13. West bluff of Manatawney Creek, ⅙ mile north of Rabbit Hill (2, p. 162).
14. David Yoder quarry, ½ mile northeast of Manatawney (Pleasantville) (2, p. 165).
15. Williams quarry, ½ mile northwest of Manatawney (Pleasantville) (2, p. 165).
16. Schollenberger quarry, east of Pine Creek, ½ mile north of Manatawney (Pleasantville) (2, pp. 165-166).
17. Weidners quarry, 1 mile south of Lobachsville (2, p. 166).
18. John Keim quarry, 1 mile west of Lobachsville (2, p. 167).
19. Deisher quarry, 1-½ miles northeast of Friedensburg (2, p. 168).
20. Bertolet quarry, 1 mile east of Friedensburg (2, p. 169).
21. Kauffman quarry, 1-½ miles southeast of Friedensburg (2, p. 170).
22. Ellis Winter quarry, 1 mile northwest of Griesemersville (2, p. 171).
23. S. Houck quarry, 1-½ miles northwest of Griesemersville (2, p. 171).
24. Guldin quarry, ¾ mile north of Yellow House (2, p. 172).
25. Weaver quarry, 2 miles northwest of Griesemersville (2, p. 173).
26. Seth Grim quarry, 1-¾ miles northwest of Griesemersville (2, p. 173).
27. Kemmerer quarry, 1-½ miles west of Griesemersville (2, p. 174).
28. Sneider quarry, 1 mile northeast of Oley Line (2, p. 175).
29. Bauderbusch quarries, ¾ mile east of Oley Line (2, p. 176).
30. Ezra Griesemer quarry, 1 mile southwest of Griesemersville (2, p. 176).
31. Fischer quarries, 1 mile southwest of Griesemersville (2, p. 177).
32. Herbein quarry, 1-¼ miles southwest of Griesemersville (2, p. 177).

33. Marquart quarry near Limekiln Creek, 1 mile southeast of Oley Line (2, p. 178).
34. Quarry ½ mile southeast of Oley Line (2, p. 179).
35. A. Knabb quarry, ½ mile northwest of Oley Line (2, p. 180).
36. S. Kaufmans quarry, ½ mile south of Oley Line (2, p. 185).
37. Ritter quarry, ¾ mile east of Jacksonwald (2, p. 186).
38. Tyson quarry, ½ mile east of Jacksonwald (2, p. 187).
39. Big Dam quarry, along Schuylkill River, 1-½ miles southeast of Reading (2, p. 189).
40. Exposure on P. & R. cut, 1 mile south of Reading (2, p. 189).
41. Long's quarry, right bank of Schuylkill River, opposite south part of Reading. Analysis by Booth, Garrett and Blair (2, p. 195).

TRIASSIC LIMESTONE

The most extensive development of the Triassic limestone conglomerate is along the northwest boundary of the Triassic strata in the vicinity of Reading, Berks County. The most easterly locality is at Clayton. This conglomerate appears at the surface just east of Bechtelsville and overlies the ore in the Boyertown magnetite iron mines. From Athol (Amityville) to Stonersville it is unusually well-developed, forming the surface rock over almost the entire southern half of Amity Township. Another lens with a width of outcrop of about 2,000 feet appears near Antietam Creek about 2 miles south of Jacksonwald and extends westward through Neversink and Fritz Island to a point a short distance beyond Schuylkill River. It forms most of Poplar Neck and the peninsula lying to the west and good exposures may be seen in some of the railroad cuts. West of Schuylkill River it has been observed in a few places but particularly at the old Wheatfield Ore Banks, three-fourths mile east of Fritztown.

In the Berks County localities the limestone conglomerate varies greatly. In some places it has a large admixture of sandstones and shale fragments. The size, shape and color of the fragmental material vary.

Near Klapperthall about 2 miles southeast of Reading, an attractive variety of the Potomac marble (limestone conglomerate) outcrops along the railroad. Angular fragments of white, gray, mottled and reddish crystalline limestones are enclosed in a red sand matrix. Some specimens from the locality will take a high polish and are especially handsome. The rocks near the surface are somewhat broken by frost action so that it might be difficult to secure large building blocks but it is probable that better could be obtained at greater depth. An illustration of this stone is given on plate 4. It is possible that at this locality and perhaps at some others attractive decorative stone for interior work might be obtained. The stone is almost identical with the marble formerly quarried along the Potomac River in Maryland and Virginia except that the fragments are somewhat smaller, averaging less than an inch in diameter.

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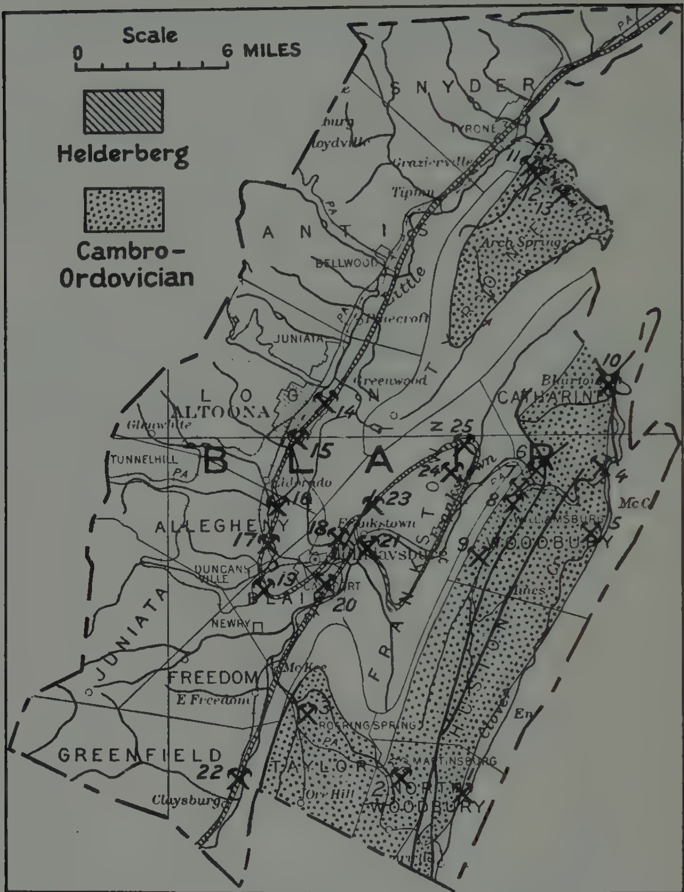

Fig. 5. Limestone areas in Blair County.

1. Homer K. Schriver
2. C. S. Baughman
3. Snowberger and McGee and M. A. Showalter
4. Juniata Limestone Co.
5. Clover Creek quarries of Pittsburgh Limestone Co.
6, 7. St. Clair quarry of Pittsburgh Limestone Co.
8. Gildea Stone Co.
9. McKinney Steel Co.
10. Blair Limestone Co.
11. Tyrone Forge quarry of American Lime and Stone Co.
12. Sterling Lime and Stone Co.
13. Cambria Steel Co.
14. W. H. Delancey
15. Bell and Bockle
16. John Ellenberger
17, 18. American Lime and Stone Co.
19. Duncansville Lime and Stone Co.
20. Chimney Rock Limestone Co.
21. Gildea Stone Co. (Cedar Ridge quarry)
22. McKinley Dodson
23. Geeseytown Cement Products Co.
24. Canoe Creek Stone Co.
25. Calcium Products Co.

BLAIR COUNTY

Blair County is well supplied with limestones belonging to several different formations. The stone varies much in chemical composition and physical characteristics and so is adaptable to many different uses. The Cambro-Ordovician and Helderberg limestones are of the greatest importance, although some limestones of value are contained in the rocks of other geologic periods, especially the Carboniferous.

Limestones have been quarried on a small scale in scores of places in the county, and in a few localities have been extensively worked.

The stratigraphic geology of Blair County has not been described since the work of the Second Geological Survey, with the exception of a small area in the western part that is included within the Ebensburg and Patton quadrangles. Charles Butts worked in the southern half of the county in 1908 and 1913 and published a stratigraphic column for Blair and Huntingdon counties.[8] In abbreviated and slightly modified form this table is here given.

*Geologic column for Blair and Huntingdon counties**

Limestones are set in italic

	Feet
PENNSYLVANIAN	
Allegheny group	200±
Shale and sandstone, with workable coal beds.	
Pottsville series	130-280
Mainly sandstone, clay, and shale, with coal locally in middle.	
Homewood sandstone	
Mercer shale	
Connoquenessing sandstone	
MISSISSIPPIAN	
Mauch Chunk series	180-1000
Mainly lumpy, red shale or mudrock. Mostly of Chester age.	
Loyalhanna limestone—Trough Creek limestone	
Siliceous crossbedded limestone to west (Loyalhanna limestone); gray and red, partly argillaceous limestone to east (Trough Creek limestone of I. C. White) Warsaw age?	
Pocono series	1130-1400
Thick-bedded, gray sandstone; Burgoon member at top; shale, red shale, and sandstone below. Conglomerate at bottom to east. Osage age.	
Burgoon sandstone.	
Cuyahoga sandstone.	
Berea sandstone.	
DEVONIAN	
UPPER DEVONIAN	
Catskill group	2000-2500
Lumpy, red shale or mudrock, thick-bedded, micaceous red sandstone. 80 per cent red. Gray and greenish shale and gray sandstone with marine fossils, 20 per cent.	

* This column has been arranged to follow the official section of the Pennsylvania Geological Survey, although the author prefers the U. S. Geological Survey section which does not include the Canadian System.

Chemung group	2400-3300
Mostly shale with thin sandstone layers.	
Saxton conglomerate	
Allegrippis sandstone	
Pine Ridge sandstone	
Portage group	
Brallier shale	1350-1800
Fine-grained, siliceous shale in thick, even layers revealing their fissility on weathering. A few thin fine-grained sandstone layers. Fossils small and very scarce. Upper Portage.	
Harrell shale	250
Dove and black fissile (paper) shale. Black at bottom to west (Burket member). Black and dove interbedded to east.	
Burket black shale	
MIDDLE DEVONIAN	
Hamilton group	800-1200
Hackly shale at top, weathers green; impure limestone layers in top 10 to 20 feet.	
Tully limestone—1 foot limestone at very top.	
Marcellus group	150
Black fissile slate	
Onondaga group	50
Dark shale with *limestone* layers.	
LOWER DEVONIAN	
Oriskany group	
Ridgeley sandstone	100
Coarse thick-bedded sandstone. Common Oriskany fossils plenty. Upper Oriskany.	
Shriver limestone	200
Thin-bedded siliceous limestone. Oriskany fossils. Lower Oriskany.	
Helderberg group	150
Thick-bedded gray limestones (Keyser, Coeymans, New Scotland).	
SILURIAN	
Cayugan series	
Tonoloway limestone group	450
Thin-bedded limestone. Fossils few.	
Wills Creek group	600
Dove, calcareous, fissile shale, a little *limestone*. Fossils very scarce. Bloomsburg red member, shale red and green, impure *limestone* and red sandstone—bottom 50 to 150 feet.	
Bloomsburg red member	
Limestone and shale; fairly fossiliferous.	
Niagaran series	
McKenzie limestone group	275±
Clinton group	800
Mainly greenish shale weathering purplish. Some sandstone. Thin but workable iron ore beds. Rather fossiliferous.	
Keefer sandstone	
Marklesburg ore	
Frankstown ore	
Block ore	

Medinan series		
Tuscarora group	Thick-bedded white quartzite. Extensively used for silica brick. Called ganister.	400
SILURIAN or ORDOVICIAN		
Juniata group	Red lumpy shale or mudrock, red and greenish gray sandstone. Some finely cross laminated. No fossils.	850
Oswego group	Medium thick-bedded gray sandstone. Some fine cross laminated. No fossils. Bald Eagle sandstone of Grabau. Oneida conglomerate of Pennsylvania Second Geological Survey.	800
ORDOVICIAN		
Upper Ordovician		
Reedsville shale	Thick, dark, rusty-weathering sandstone at top. Maysville age. Shale with thin *limestone* layers in upper half. Eden age.	1000
Middle Ordovician		
Trenton limestone group	Thin-bedded black limestone weathering with a gray film on surface. Sparsely fossiliferous.	320
Rodman limestone group	Dark crystalline limestone weathering with a rough granulated surface; very characteristic and persistent. Fossiliferous. Upper Black River.	30
Lowville limestone group	Dark, thick-bedded, pure limestone, glassy to fine-grained. Extensively quarried for flux. Lower Black River.	180
CANADIAN		
Carlim limestone group	Dark, fine grained limestone, extensively quarried for flux. Fossils scarce except in Lemont argillaceous limestone member. Lemont member impure, not quarried.	180
Lemont limestone		
Beekmantown series		
Bellefonte dolomite	Thick-bedded dolomite yielding much dense chert. Fossils scarce.	1000
Axemann limestone	Thin-bedded blue limestone with dolomite layers. Fossils.	100
Nittany dolomite	Thick-bedded, cherty dolomite. Fossils, but not abundant.	1000
Ozark series		
Larke dolomite group	Thick-bedded, coarse, steely blue dolomite.	250
Mines dolomite group	Cherty dolomite, oolitic, yields much oolitic and platy scoriaceous chert. *Cryptozoon*, 2 species, common.	250

Gatesburg group	1750
Thick-bedded, steely blue, coarsely crystalline dolomite with many interbedded quartzite layers up to 10 feet thick. Surface deeply covered with sand and strewn with quartzite bowlders. Considerable silicified oolite. *Ore Hill limestone* member, thin bedded, blue limestone.	
CAMBRIAN	
Elbrook group.	
Warrior limestone	250
Thick- and thin-bedded, blue limestone with thin, siliceous, shaly layers or partings. A few thin quartzite layers and an occasional bed of limestone full of large well-rounded quartz grains. Some oolite. *Cryptozoon* common.	
Pleasant Hill limestone	600
Thick-bedded limestone at top, fossils. Argillaceous, thin-bedded limestone at bottom weathering to shale.	
Waynesboro group	250±
Sandstone, conglomerate and red and greenish shale.	

In the table as published by Butts, the Larke dolomite, Mines dolomite and Gatesburg formation are classified as belonging to the Ozarkian system and the Warrior limestone, Pleasant Hill limestone and Waynesboro formation as constituting the Cambrian system.

CAMBRO-ORDOVICIAN LIMESTONES

The Cambro-Ordovician limestones form the floor of Morrisons Cove and Sinking Valley. Morrisons Cove is bounded on the east by Tussey Mountain and on the west by Dunning, Short, Loop, and Lock mountains, all of which constitute a single mountain ridge with different names applied to different parts. The cove extends into Fulton County to the south and into Huntingdon County to the north. Sinking Valley is enclosed in a sharp loop of Brush Mountain. Morrisons Cove at the southern end of the county is about 8 miles wide, from Martinsburg to Williamsburg about 4 miles, and from Williamsburg to the northern end of the county 2½ to 3 miles. Sinking Valley is about 4 miles wide at the northern boundary of the county and gradually narrows to a point southward.

As shown in the table above, the Cambrian and Ozark of the region have been divided into 6 different formations, all except the lowest of which consist almost entirely of limestone and dolomite and aggregate 3100 feet in thickness. The Ordovician and Canadian are divided into 8 formations all of which consist almost exclusively of limestone or dolomite with the exception of the uppermost. These seven calcareous formations aggregate 2810 feet in thickness. Lack of detailed stratigraphic data prevents the discussion of each of these formations separately.

The structure of Morrisons Cove and Sinking Valley, the two valleys containing all the Cambro-Ordovician limestones of the county is anticlinal. If all the material that has been removed by erosion could be restored, both of these regions would be high, rounded, elongated ridges with the center of both arches several thousand feet higher than the high ridges now bounding these valleys. In a gen-

eral way from near the center of the valleys the strata can be observed to dip east as one goes east and west as one proceeds in the opposite direction, and at both sides of the valley the highest (youngest) limestones of the Ordovician dip beneath shale strata which constitute the upper member of the Ordovician. In the southern part of the county, in the vicinity of Roaring Spring and Martinsburg and southward, there are two major folds instead of one and this is the cause of the much wider valley there.

A recognition of the major structure of these valleys is of the greatest importance to anyone seeking limestones of any particular type. All of the limestones below the Beekmantown are either dolomitic or siliceous or both and should therefore be sought toward the center of the valley whereas the strata above the Beekmantown, in the main, are low in both magnesia and silica and they outcrop near the margins of the valley close to the shales that appear on the lower slopes of the enclosing mountain ridges. The Beekmantown outcropping towards the sides of the valleys is mainly dolomitic although containing some low magnesian limestones.

Locally there are other complications of structures—minor folds and faults—that interfere with the rigid application of the general principle of anticlinal valleys. Some of the faults cause repetition or elimination of certain strata so that detailed geologic investigations should be made before opening or equipping any large quarry.

The dolomitic and siliceous limestones are hard and especially serviceable for highways and concrete work; the low magnesian pure limestones are desirable for flux and high-calcium lime. Both varieties of stone have been used for agricultural lime and for building stone.

In the southern end of Morrisons Cove the only recent activities are near Martinsburg and at Roaring Spring. Lime burning was once carried on at many places but most of these operations have ceased because of the competition with some of the large companies in adjoining counties. The quarrying of stone for highway construction is profitable when roads are being built in the vicinity. A township quarry has been worked about three-fourths mile northwest of Henrietta.

Homer K. Schriver has a quarry and stone kiln where he has burned lime about half a mile southeast of Clover Creek (Fredericksburg). The plant was idle when visited in 1929. The quarry is roughly semicircular, about 150 feet in width, with a 15-foot working face. It is being worked down the dip. The strata strike N32°E. and dip 35°SE.

Section at Schriver quarry

	Ft.	*in.*
Shaly limestone	2	0
Massive, grayish-blue limestone, in part coarsely crystalline, numerous fossils, crinoids, bryozoa, etc.	5	0
Bluish-gray limestone part of which is somewhat shaly	5	8
Dark blue limestone with iron stains along fractures	2	10
Grayish-blue limestone	3	2

No chemical analyses are available but the stone appears to be low in magnesium and of good grade throughout with the exception of the uppermost shaly material.

At the south edge of Martinsburg, C. S. Baughman has a small quarry. He crushes stone during the summer and burns lime in the winter. He crushes 50 tons per day and can burn 250 bushels of lime in the two stone lime kilns he has constructed. The beds strike N32°E. and dip 20°NW. The quarry face is about 20 feet high. The stone is low magnesian, rather coarsely crystalline, grayish blue, and contains only fragmentary fossils. The beds range from 1½ to 3 feet in thickness. Calcite veins are common.

Just north of Roaring Spring there are two limestone quarries. The New Enterprise Stone & Lime Co. has a rather large quarry where they crush stone and burn lime. This quarry was acquired from Snowberger & McGee in 1930. They have 2 stone lime kilns and burn on an average about 500 tons per year for local farm use. They have produced 10,000 tons of crushed stone a year with a gyratory crusher. The strata have a strike of N30°E. and dip 82°SE. The quarry face is about 200 feet long and 60 feet high. The beds are rather thick. The stone is gray to bluish black and is low in magnesia. Calcite veins are prominent in part of the quarry. Some layers appear to contain appreciable amounts of argillaceous matter but the average stone is of good quality either for roads or for lime.

Near by is the quarry of M. A. Showalter where the beds strike N22°E. and dip 86°SE. The stone is massive, beds varying from 3 to 6 feet in thickness. Calcite veins are numerous. Stylolites developed along fault planes that had displaced and offset calcite veins were noted. Only crushed stone is produced.

In the vicinity of Williamsburg there are several extensive limestone quarries that have furnished a large amount of fluxing stone.

At Carlim, the Juniata Limestone Co. has a number of openings extending for almost a mile along the west bank of Frankstown Branch of Juniata River. The structure observed in the various places is extremely complex. Toward the north the beds dip east about 45°, but southward the dip is from 75° to 90° eastward and in several places the dip is north. The strata are closely folded and faulted and many calcite veins through the stone. A number of layers contain too much silica for fluxing stone. The quarries were opened to supply fluxing material for the Cambria Steel Co. and up to 1920 furnished a large quantity of stone with a silica content from 3 to 5 per cent. The poor stone has either been left or was quarried and crushed for ballast and concrete.

About 2 miles southeast of Williamsburg the Pittsburgh Limestone Co. has several quarries along Clover Creek and the Blair Limestone Co. also formerly operated several quarries along the same creek. The operating quarries are mainly along the west side of the creek but at the extreme south end of the property there is a large opening in good stone on the east side of the creek. This one was worked below the level of Clover Creek with a face almost 200 feet high. In all the quarries the strata dip to the east toward Tussey Mountain but at different angles. Toward the north, the dip averages about 45° but southward some of the beds have dips of 5° to 15° E. There are about 450 feet of quarrying stone between the overlying Trenton and the underlying Bellefonte dolomite, a thickness somewhat greater than Butts gives for the combined thickness of the Rodman, Lowville, and Carlim. All of this was used for flux except about 30 to 40 feet of sandy siliceous to slaty stone that was left

in the quarry where practicable. The best stone, the Lowville, lies above the poor stone. The faces of the west quarries are about 160 feet high.

On the opposite side of the valley at Ganister, 1½ miles northwest of Williamsburg the same strata worked in the east side of the valley have likewise been extensively quarried. On the north side of the river at Ganister the St. Clair Limestone Co., a subsidiary of the Pittsburgh Limestone Co. has a quarry. Across the river to the southwest are the Franklin Forge quarry of the Pittsburgh Limestone Co., the quarry of the American Steel and Wire Co., now worked for road stone by the Gildea Stone Co., and the quarry of the McKinney Steel Co. All of these have been worked for fluxing stone, and all have the same 30 to 40 feet of siliceous rock between the two belts of good stone. The upper band contains the better stone. The beds dip about 60°W. In the Franklin Forge quarry the two bands have been opened separately and a tunnel run through the poor rock to connect the two quarries. At the St. Clair quarry the lower band of fluxing stones has not been opened yet. All of these quarries have passed their zenith.

An average analysis of 221,000 tons of fluxing stone shipped from Franklin Forge in 1920 is as follows:

$CaCO_3$, 91.00; $MgCO_3$, 4.85; SiO_2, 3.66: Fe_2O_3, .52; Al_2O_3, 1.39; S., .134; P., .006; Moisture, 1.16.

The Pittsburgh Limestone Co. has furnished the following analyses of the stone in the St. Clair quarry. The strata dip 52°W. No. 1 is the uppermost bed worked. Between No. 1 and the overlying Reedsville shale are about 7 feet of high silica limestone that is not used. The silica also increases in the ledges lying beneath No. 22. The thicknesses for the different beds given are not uniform throughout the quarry but the values given represent fair averages.

Summary of samples representing cross-section of limestone deposit in St. Clair quarry.

Bed	Thickness across bedding in feet	Analysis of average samples Silica	Phosphorus	Sulfur
1	12	4.87	.014	.052
2	5	3.03	.010	.017
3	5¾	7.25	.011	.044
4	12¼	6.26	.010	.140
5	15	4.14	.008	.134
6	10¾	1.84	.006	.067
7	5¾	.92	.005	.014
8	10¾	3.44	.014	.125
9	14½	3.26	.010	.080
10	8	5.01	.016	.069
11	10¾	3.60	.011	.118
12	14	2.91	.009	.069
13	8	4.34	.009	.029
14	27½	2.12	.008	.038
15	26	1.41	.006	.039
16	5	3.14	.012	.050
17	9¾	6.55	.014	.144
18	10¾	4.86	.013	.133
19	14½	2.43	.006	.038
20	6¾	1.82	.008	.026
21	5¼	2.96	.010	.056
22	4	4.39	.020	.094
Total	242	Avg. 3.41	Avg. .010	Avg. .072

Analyses of typical samples from groups in foregoing table

	No. 1	No. 4	No. 14	No. 20
SiO_2	5.63	3.33	2.16	1.35
$Fe_2O_3+Al_2O_3$	2.88	1.92	.80	1.00
CaO	50.40	52.10	53.40	54.10
$CaCO_3$	90.00	93.04	95.36	96.61
MgO	.69	.73	.96	.72
$MgCO_3$	1.45	1.53	2.02	1.51
P	.028	.014	.008	.012
S	.083	.079	.021	.025
Loss on ignition	40.16	41.45	42.86	43.02
Total	99.87	99.62	100.21	100.23

Ernest W. Greiner, Chemist.

The same ledges worked about Williamsburg no doubt extend southward on either side of the valley, but it has not been profitable to open any quarries except in the vicinity of good shipping facilities. The local demand for stone is small. Good quarrying conditions may not be found everywhere along the outcrop of these bands of good stone but doubtless there are favorable sites where quarries might be opened for profit if the demand for stone warranted the necessary expenditure.

Northward from the Williamsburg region the Blair Limestone Co., a subsidiary of Jones & Laughlin Steel Co., has five large quarries at Blairfour. Quarries Nos. 4 and 5 were in operation in 1929 but the latter has since been abandoned. In No. 4 the working face was about 750 feet long and height of face 265 feet at highest point, and in No. 5 about 800 feet long and height of face 150 feet. The beds worked in the two quarries, which are about half a mile apart, are practically the same. In No. 4, the southern one, the strike is N26½°E, with dip 40°SE. In No. 5 the strike is N26½°E, dip 38½°SE.

Generalized section, Quarry No. 5, Blair Limestone Co.

	Feet
Shaly limestones, not used	
Low silica limestones	400
High silica limestones	35
Low silica limestones	150
High silica limestones	

The two thick bands of low silica stone are quarried for fluxing stone. The high silica material has been quarried and crushed for road and concrete purposes. The stone used for flux runs from 3/4 inch to 5 inches in size. The finer material is a by-product. This is sized and the material between 3/4 and 3/8 inch is used as a concrete aggregate, in curb work and small walls, and sizes smaller than 3/8 for concrete work, top dressing for water-bound macadam roads, etc. In 1928 there was shipped from the Blairfour quarries 255,706 gross tons of fluxing stone and 28,291 tons of fine sizes.

In 1915 the quarry, as it then existed, was sampled carefully and samples analyzed. The results are given in the following table which gives a good idea of the character of the stone.

Analyses of limestone in Quarry No. 5, Blair Limestone Co.

Ledge	$CaCO_3$	Iron and Alumina	SiO_2	Width Ft.	Ledge in.
1		Above 5	12.20	0	10
2		2.12	4.87	6	0
3		Above 3	5.02	3	9
4		3.33	6.93	3	10
5		.99	1.50	6	0
6		.50	1.32	10	0
7		1.41	4.04	5	0
8		2.76	6.45	2	1
9	Shale				9
9	Missing			2	0
10	87.12	1.47	2.70	2	3
11	89.46	.89	1.67	2	3
12	87.38	1.02	1.66	1	11
13	83.69	.80	2.16	3	0
14	85.82	1.26	2.22	2	4
15	89.76	.89	1.42	2	1
16		3.61	8.50	0	8
17	94.36	.50	1.28	1	8
18	84.48	1.22	1.78	1	2
19	86.59	1.35	2.66	1	2
20	79.99	1.29	3.29	2	4
21	Missing			2	6
22	87.90	1.64	3.40	3	2
23	91.48	2.00	3.62	5	10
24	89.10	2.18	4.08	2	10
25	87.38	2.64	5.14	7	8
26	91.11	1.20	1.84	24	0
27	92.80	1.50	2.52	2	4
28		4.02	7.86	8	0
29		Over 5	12.86	18	9
30		Over 5	23.88	4	1
31		4.16	10.24	5	0
32	93.72	.94	3.80	5	6
33	89.10	1.12	4.36	5	0
34		3.94	9.30	3	8
35	76.16	1.94	4.40	3	9
36		3.24	6.20	1	4
37		2.08	5.56	1	9
38			3.20	3	8
39	95.63	.92	2.52	2	.0
40	High	.28	.62	3	2
41	99.56	.34	.46	1	6
42	98.75	.48	1.02	2	0
43	92.63	1.00	2.52	3	11
44	92.86	1.00	3.00	3	1
45		2.80	6.60	1	8
46		3.56	9.56	1	11
47	95.87	.94	2.26	2	3
48	97.94	.76	1.66	1	5
49	96.10	1.32	2.64	2	5
50	95.06	1.10	2.50	0	6
51	88.82	2.74	4.90	1	5
52	96.56	.76	1.74	5	4
53	97.94	.60	1.20	2	2
54	92.05	.80	2.22	18	8
55	93.56	1.42	3.22	2	0
56		1.54	3.06	5	0
57	86.74	1.88	5.76	7	4
57x	Missing			5	0
58	94.71	1.30	2.20	7	11
59	97.59	.70	1.46	12	0
60	95.98	.86	1.86	15	6

Ledge	$CaCO_3$	Iron and Alumina	SiO_2	Width Ft.	Ledge in.
61	97.59	.56	1.60	11	2
62	84.20	2.52	4.40	11	11
63	91.48	1.36	4.24	4	6
64	91.59	2.50	4.22	7	4
65	92.05	2.36	4.16	15	0
66	94.71	1.52	2.74	2	8
67	93.90	.96	2.20	5	4
68	92.05	2.74	3.16	3	1
69	94.83	1.56	2.38	1	5
70	93.32	1.68	2.62	7	8
71	96.44	1.26	1.08	4	3
72	95.17	1.48	2.18	5	4
73	92.98	2.18	2.44	5	8
74	91.48	2.04	3.76	13	0
75		4.64	7.24	4	6
76		4.76	8.86	1	7
77		2.08	2.16	2	5
78	96.78	1.18	2.30	3	2
79	94.47	1.82	2.82	2	11
80	95.28	1.10	2.48	1	4
81	94.94	1.04	2.44	4	4
82	86.27	1.72	2.50	5	7
83		2.82	4.76	1	0
84		4.38	6.52	1	11
85		3.04	6.26	1	7
86	94.36	1.66	3.34	1	7
87	94.36	1.36	3.00	3	6
88	93.32	2.14	4.02	0	10
89	92.75	2.38	3.08	1	10
90	94.13	1.84	2.74	1	1
91		2.64	9.18	1	2
92		2.96	9.98	1	1
93		5.02	12.86	2	2
94		5.26	13.56	2	8
				422	8

About two miles east of Tyrone, on the southeast flank of Bald Eagle Mountain there are two quarries where Rodman, Lowville, and Carlim limestones have been worked. One of these is the Tyrone Forge quarry of the American Lime and Stone Co., and the other was operated by the Pittsburgh Limestone Co. on property leased from the former company. In the former quarry the strata are slightly overturned and dip 85° to 87°SE. The quarry opening is narrow and the west face is formed by Trenton limestone that makes a sheer wall about 160 feet high. The company used the larger blocks for the manufacture of agricultural and chemical lime and sold the spalls for flux. The other quarry was worked primarily for flux. The high grade limestone ledge (Bellefonte ledge) so extensively quarried at the same horizon near Bellefonte can be recognized in these quarries but it is thinner and the stone is also somewhat less pure. In 1928 the Sterling Lime and Stone Co. leased the quarry formerly worked by the Pittsburgh Limestone Co. and since that time has been producing crushed stone. About one-half of the product is sold for road work and the remainder goes to the Interstate Amiesite Co. that has erected a plant near by. A small amount has been shipped for flux. The capacity is about 400 tons per day.

The beds in this quarry are slightly folded but in general have a southeasterly dip of 40° to 60°.

The stone used for amiesite varies from 5/8 to 1¾ inches in size according to specifications. It is dried in a rotary dryer, elevated to mixing troughs where it is moistened with a mixture of naphtha and kerosene. The asphaltic product is then added and mixed by two revolving cylinders with attached flanges and rotating in opposite directions. After the stone fragments are thoroughly coated, a small amount of lime is shovelled in. The material is dumped through sliding doors into cars below.

At Birmingham the Cambria Steel Co. operated a quarry from 1893 to 1895 and shipped large quantities of fluxing stone. The quarry was finally abandoned because of high silica. Analyses are given below. Butts (op. cit.) has described displacement by faulting of some of the strata here amounting to 5000 to 6000 feet.

While the Birmingham quarry was being worked for flux the weekly average analyses ran as follows.

Analyses of Birmingham limestone

	Averages	*Typical*
$CaCO_3$	85.80 to 91.03	90.40
$MgCO_3$	3.30 to 5.87	4.06
SiO_2	3.30 to 4.60	4.02
Al_2O_3	.40 to 1.88	.47
Fe_2O_3	.15 to .80	.45

The quarry was finally abandoned for flux as the stone was regarded as too poor in quality.

An average analysis of 190,000 tons of fluxing stone shipped from Tyrone Forge in 1920 is as follows:

Analyses of limestone at Tyrone Forge

$CaCO_3$	90.48
$MgCO_3$	5.82
SiO_2	3.80
Fe_2O_3	.51
Al_2O_3	1.23
S	.130
P	.005
Moisture	1.05

Additional analyses of Cambro-Ordovician limestones from Blair County

	1a	1b	2a	2b	3	4
$CaCO_3$	90.389	92.115	85.80 to 91.03	90.40	53.870	48.030
$MgCO_3$	2.245	4.234	3.30 to 5.87	4.06	41.320	37.670
SiO_2	------	------	3.30 to 4.60	4.02	------	------
Al_2O_3	------	------	0.40 to 1.88	0.47		
Al_2O_3, Fe_2O_3	1.682*	.189*	------	------	1.190	2.850
Fe_2O_3	------	------	0.15 to 0.80	0.45		
S	------	------	------	------	.045	.463
P	------	------	------	------	.013	.040
Insoluble	5.880	3.620	------	------	2.910	10.380

* $Al_2O_3+FeCO_3$.

	5	6	7	8	9
$CaCO_3$	78.186	78.176	91.892	54.571	94.980
$MgCO_3$	17.510	10.746	2.875	44.180	3.866
SiO_2	--------	--------	--------	--------	--------
Al_2O_3 } Fe_2O_3	1.126	1.850	0.640	0.234	0.264
S	0.085	0.149	0.097	0.002	0.053
P	0.015	0.029	0.022	0.003	0.011
Insoluble	3.210	8.570	4.380	1.330	0.910

1. Two limestone quarries near Tyrone. a. Hard and compact; mottled with calcite; light bluish gray. b. Irregularly seamed and mottled with calcite; hard and compact; dark gray; with conchoidal fracture. (2, p. 306)

2. Birmingham quarry of Cambria Steel Co. a. Range of many weekly averages. b. Typical weekly average. Analyzed by Cambria Steel Co.

3. Keystone Zinc Co. Near Birmingham. Conglomerate-like; irregularly seamed with white crystalline carbonate of lime; color, various shades of gray and bluish gray. (2, p. 307)

4. Borie property. About 6 miles southwest of Birmingham. Wall rock at deep shaft. Hard, compact; minutely cystalline, bluish gray. (2, p. 307)

5. Springfield Furnace quarry. 5 miles southwest of Williamsburg. Irregularly seamed with thin veins of white crystalline carbonate of lime; generally very hard and tough; dark blue. (2, p. 306)

6. Rodman Furnace quarry No. 1, South of Roaring Spring. Fine grained; seamed with calcite; brittle,; bluish gray. (2, p. 306)

7. Rodman Furnace quarry No. 2. South of Roaring Spring. Coarse grained; sparkling with calcite; bluish gray, with rough irregular fracture. (2, p. 306)

8. Rodman Furnace quarry. On railroad south of Roaring Spring, near Rodman furnace. Fine grained; very hard; pearl gray. (2, p. 306)

9. Mt. Etna Furnace quarry. 5 miles north of Williamsburg. Irregularly seamed with calcite; dark bluish gray, with conchoidal fracture. (2, p. 306)

HELDERBERG LIMESTONES

The Helderberg limestones are well developed in Blair County and have been extensively worked in several places. The band of outcropping strata, forming the floor of Bald Eagle Valley, extends in a southwesterly direction through Tyrone and the eastern part of Altoona to a short distance beyond Duncansville and near Frankstown to a point a few miles north of Canoe Creek. It then turns to the southwest and follows along the west flank of Lock, Loop, Short, and Dunning mountains to the Bedford County line, passing through Flowing Spring, Reservoir, and McKee Gap.

The Helderberg (including the Tonoloway) limestones within the county are more than 400 feet thick. There is a great variation in the character of the material, as indicated by the following detailed section by Reeside (7, pp. 205-206). The lists of fossils contained in the different members given by Reeside are omitted.

Section at Lincoln and Fifteenth Streets, Tyrone

Concealed; scattered outcrops of dark gray and brown fissile shale; a few bands of impure limestone.

	Feet
Helderberg limestone:	
New Scotland limestone member:	
Limestone, medium bedded (1 foot), fine grained, light gray; contains chert lentils and shale laminae	4.4

	Feet
Shale, weathers brown	1.4
Limestone, impure fine grained, thin bedded light gray, in courses 8 inches thick, with shale partings	2.6
Limestone, shaly weathered	.8
Limestone, massive, heavy bedded, coarse grained, crystalline, gray; much interbedded chert	4.8
	14.0
Coeymans limestone member:	
Limestone, very impure, shaly, yellowish	3.8
Limestone, somewhat weathered, light gray, coarsely crystalline; line of chert nodules (2 by 10 inches) near the top	2.0
Limestone, massive, coarsely crystalline, dark	2.5
	8.3
Keyser limestone member:	
Limestone, single bed, light gray, fine grained, impure	1.1
Limestone, very shaly, light gray	1.8
Limestone, light gray, fine grained, platy	.8
Shale, brown, weathered	2.9
Limestone, light gray, fine grained, platy	1.1
Shale, brown, weathered	2.0
Limestone, impure, brownish gray, very platy; breaks into sheets half an inch thick	4.6
Limestone, pure grained, brownish gray; in two beds separated by brown shale; has conchoidal fracture	2.7
Limestone, shaly, banded, dark gray; contains carbonaceous films	1.5
Limestone, composed entirely of stromatoporoids	2.3
Limestone, shaly, yellowish gray. Scattered heads of stromatoporoids	2.0
Limestone, composed entirely of stromatoporoids; under surface very irregular	3.2
Shale, brown, weathered	.4
Limestone, composed entirely of stromatoporoids and corals; under surface irregular	5.9
Limestone, buff, fine grained, shaly	1.5
Limestone, extremely massive, composed entirely of corals, Bryozoa and stromatoporoids	9.4
Limestone, with profusion of corals and stromatoporoids	6.0
Shale	.6
Limestone, coarsely crystalline, gray	1.0
Limestone, coarsely crystalline, gray. Scattered stromatoporoids	3.0
Limestone, coarsely crystalline, gray	3.5
Limestone, massive, coarsely crystalline	7.7
Limestone, thin bedded (1 to 6 inches), crystalline, light gray	3.5
Limestone, massive, coarse grained, light gray	5.0
Limestone, thin bedded, gray and shale	1.5
Limestone, brownish gray to buff, in single bed standing out as a ridge; coarse, crinoidal	3.9
Limestone, thin bedded, coarse, gray	.6
Shale	.4
Limestone, buff, massive, coarse grained, crystalline	3.6
Limestone, brownish gray, single bed. Fragments of fossils in surface	2.5
Limestone, thin bedded, buff; drab on fresh fracture	2.3
	88.3
Tonoloway limestone:	
Limestone, massive, buff	2.0
Limestone, massive, fine grained, buff, cherty	1.4
Limestone, massive, fine grained, buff, banded	6.4
Limestone, fissile, banded, buff; drab on fresh fracture	11.7
Shale, buff, calcareous, contorted and in places apparently brecciated	7.8
Shale, weathered, brown, earthy	1.0

	Feet
Limestone, massive, fine grained; weathered surface light gray, fresh fracture drab; banded; contains some thin chert lentils	6.7
Limestone, platy, banded, fine grained, light gray	2.3
Limestone, platy, laminated, fine grained, buff	.9
Limestone, buff to light brown, platy; much geodal calcite in small crystals	1.3
Limestone, fissile, light gray	2.3
Concealed; probably platy limestone	4.0
Limestone, light gray, platy, impure	1.0
Limestone, light gray in solid bed; platy fracture	3.3
Limestone, platy, fine grained, buff	4.0
Concealed; brown shale in part	15.0
Limestone, platy, buff	2.5
Shale, calcareous and fine siliceous oolite (?); weathered surface ferruginous, brown; bedding irregular	2.4
Limestone, blocky, fine grained, buff	1.3
Shale, weathered brown	2.5
Limestone, platy, fine grained, buff	2.3
Shale, calcareous, much weathered; some fine grained sandy (?) layers (siliceous oolite?) stand out	10.3
Shale, calcareous, buff to light gray	1.5
Limestone, fairly pure, fine grained, buff, blocky fracture	4.0
Limestone, buff, platy, laminated in part	6.3
Limestone, shaly, platy, yellowish; many geodal calcite masses with large fine crystals	5.0
	109.2

The Helderberg limestones in the region have been quarried in many places for lime, flux, and crushed stone for concrete and highway construction. For agricultural lime, crushed stone, and ordinary flux a large portion of the rocks can be used although even for these purposes some of the shaly beds must be discarded. Near the base of the Keyser formation there is a persistent bed of extremely pure massive limestone that has been quarried for chemical lime and high grade flux. It is best developed in the Frankstown region where it averages about 25 feet in thickness and is known as "calico rock". It is a compact bluish gray containing numerous small "eyes" of white calcite which in the weathered rock are stained a dull red.

In Bald Eagle Valley from the Centre County line to Tyrone there has been little utilization of the Helderberg limestones. In Tyrone they have been quarried but not for many years. Between Tyrone and Altoona there are several long-abandoned openings where small quantities of stone have been taken out probably for burning for agricultural lime.

In 1929 only one limestone quarry was in operation in the Altoona region. This was a small quarry in the northeast part of Altoona worked by W. H. Delancey for crushed stone. About 40 feet of the Keyser member of the Helderberg was being quarried. The beds dip about 45° west but a short distance away are practically vertical. Fossil corals well preserved are abundant so that the rocks practically constitute an ancient coral reef. The capacity of the plant is only 40 to 50 tons per day. The product is used principally for various concrete structures in Altoona. It has been accepted for water-bound macadam roads but not for concrete roads.

In the east and southeast part of Altoona the Helderberg limestones have been worked for lime in the past but in recent years the demand for crushed stone has increased so that all material quarried

during the last decade has been sold for concrete and highway purposes. One of the principal quarries was that of Bell & Bockle on the hill just east of the city. The layer of pure limestone of the Keyser formation is present but where exposed contains numerous caves and clay pockets. On the east side of the creek north of the fair grounds there are several exposures of Helderberg limestones and plans were formed for opening a quarry there. A quarry has been opened in these strata near Canaan and was being worked in 1929 by John Ellenberger.

In the region of Hollidaysburg and Frankstown the Helderberg has been quarried in a number of places. Formerly much stone was burned here for lime, part of which from the best bands of stone was of excellent quality and used in the chemical manufacturing industries. Most of these quarries are now idle or producing crushed stone.

The American Lime and Stone Co. has operated in two localities near Hollidaysburg. The first place is about 1½ miles northwest of the city where the layer of pure limestone was worked for chemical lime. There are 3 kilns near the quarry. The quarry was later operated by a leasing company that took out the impure underlying rock for highway use. A stratum containing great heads of corals of the *Stromatopora* type overlies the pure limestone. The other locality is near the top of the hill about midway between Hollidaysburg and Frankstown where openings extend in a line for almost a mile. The stratum of "calico" limestone about 25 feet thick has been extensively quarried for the manufacture of chemical lime, and the underlying and overlying impure beds for crushed stone.

Section exposed in Frankstown quarries

	Feet
Impure, thin-bedded, granular limestone	20
Shaly limestone disintegrating to a clay containing calcareous fossiliferous nodules	3
Pure massive limestones ("calico" rock)	25
Impure thin-bedded limestone	?

The strata dip about 35°SE. The pure limestone is especially sought but as it dips beneath the impure layers, it can be quarried economically only when there is sale for the overlying impure material as crushed stone. The granular limestone would make a fair grade agricultural lime were it not for the fact that it breaks up into a powder in the kilns. The lime made from the good stone is sold as lump lime and is used mainly in the manufacture of paper. The following analyses of this lime were made in the laboratories of the Williamsburg Mill of the West Virginia Pulp and Paper Co. between December 1918 and March 1919. Each represents an average shipment of 10 cars of lime.

Analyses of lime made at Frankstown quarries

CaO	92.52	93.53	94.23	91.91	90.60
MgO (by difference)	1.47	1.14	1.25	1.10	1.51
SiO_2	3.96	3.12	2.44	4.04	3.56
$Al_2O_3+Fe_2O_3$	1.44	1.60	1.46	2.20	1.72
Loss on ignition	.61	.61	.62	.75	2.61
CaO	89.59	91.20	93.12	93.22	91.41
MgO (by difference)	.60	2.68	1.22	1.31	1.22
SiO_2	7.42	3.98	2.84	3.02	3.30
$Al_2O_3+Fe_2O_3$	1.80	1.80	1.24	1.65	1.92
Loss on ignition	.59	.34	1.58	.81	2.15

Half a mile south of Duncansville there is a quarry operated by the Duncansville Lime and Stone Co. The "calico" stratum, about 25 feet thick, is burned for agricultural lime and the overlying less pure beds crushed for road metal. The lime burning is subordinate to the production of crushed stone. The beds are considerably folded and are displaced by a fault that passes through the quarry. The overlying strata are a 3-foot bed of impure nodular limestone and above that granular gray stone of fair quality.

About one mile south of Hollidaysburg the Chimney Rock Limestone Co. has a quarry in which the high grade "calico" rock, from 20 to 25 feet in thickness, is quarried and burned for lime in the winter. Other layers are worked to obtain crushed stone. The quarry face was 97 feet in height in 1929. About one mile southwest of this quarry is a small abandoned one formerly worked by Chet Robertson to obtain stone for crushing.

On the east side of Juniata River opposite Frankstown the Gildea Stone Co. is working a quarry for road metal. It is called the Cedar Ridge quarry. The "calico" rock is present but is only 6 to 10 feet thick. The balance of the stone is dense blue but with many calcite veins running in every direction. The capacity is about 150 tons per day.

About one mile north of Claysburg, McKinley Dodson has a small quarry in the Helderberg. He burns about 6000 bushels of lime annually. The beds strike N9°E, dip 64° NW. A thickness of about 25 feet is exposed. About 1½ miles south of Claysburg a similar quarry was worked by Thad Knisely up to 10 years ago.

About half a mile northeast of Frankstown, a small quarry is operated by the Geeseytown Cement Products Co. for the purpose of obtaining limestone to be used in the manufacture of cement blocks, curbing stone, drain pipes, and ornamental stone. The quarry was opened in 1923.

Section in quarry of Geeseytown Cement Products Co.

	Ft.	*in.*
Grayish-blue, medium hard limestone	5	0
Clay seam		4
Massive, hard, crystalline limestone	8	0
Dark grayish blue limestone	12	0

The beds strike N30°E and dip 34°SE. The overburden is a brownish yellow sandy soil which is shot down with the rock. The stone is loaded by hand and sent to the crusher where it is reduced to a size of ¼ or ¾ inch depending upon the use for which it is intended. Some stone is sold at times as crushed stone but most of the product goes into concrete articles. The mixture used is 1 part cement, 2 parts sand, largely river sand and gravel obtained from the Pittsburgh region, and 3 parts crushed limestone. The usual size of cement block made is 8 by 8 by 16 inches. The capacity is 800 blocks per day. The cement pipes made range from 15 to 24 inches in diameter.

About 1½ miles northwest of Canoe Creek Station are the operations of the Canoe Creek Stone Co. At one time a quarry was worked here by the Jones & Laughlin Steel Co. for flux. The present company is now working for crushed stone alone, although until recently they

separated the high grade stone which is 30 to 40 feet thick and sold it for flux or burned it for chemical lime. The strata are the same as those in the quarries near Frankstown. The quarry face is 600 to 700 feet long and 200 feet high. There are some bad caves most of which are filled with clay. Stone is readily sorted as it is loaded by hand. The annual capacity of the company is given as 150,000 tons of crushed stone.

The same beds were once worked in the same ridge about 1½ miles to the southwest and 2 miles to the northeast of the Canoe Creek operations. At the latter place a company known as the Calcium Products Co. made chemical lime and obtained some high-grade open-hearth fluxing stone from the 30-foot layer of "calico" rock. The beds strike N70°E and dip 15°S. The beds quarried are overlain by 3 feet of shaly material upon which rests a bed of massive limestone about 20 feet thick. An average of 3 samples analyzed by the Cambria Steel Co. gave the following results.

Analysis of Helderberg limestone, 2 miles north of Canoe Creek Station

$CaCO_3$	95.00
$MgCO_3$	2.25
SiO_2	1.25
S	.04
P	.004

The following analyses of the high grade limestone of the Helderberg once used for flux in near by iron furnaces are published in Report T of the Second Geological Survey of Pennsylvania.

Analyses of Helderberg limestones, Blair County

	1a	*1b*	*1c*
$CaCO_3$	95.664	95.089	95.571
$MgCO_3$	1.547	1.581	1.521
$Al_2O_3+Fe_2O_3$	.842	.644	.570
S	.103	.029	.027
P	.015	.020	.009
Insoluble residue	2.500	3.000	3.020
Total	100.671	100.363	100.718

	2a	*2b*	*3*	*4*	*5*
Fe_2O_3			.745*	.615*	.534*
$CaCO_3$	97.32	97.82	95.251	96.164	84.782
$MgCO_3$	.19	.11	2.265	1.589	3.859
Al_2O_3	.52	1.34	.054	.035	.043
S	None	None	.053	.070	.053
P	.017	.005	.003	.005	.004
Insoluble Residue	2.96	1.75	1.800	1.615	10.850
	101.01	101.03	100.171	100.093	100.125

* Iron calculated as the carbonate.

1. a, b, c—Upper, middle and lower divisions of Baker quarry, 2 miles south of Altoona. S. S. Hartranft, analyst.

2. a, b—Cresswell quarry of Cambria Iron Co., 2 miles northwest of Hollidaysburg. T. T. Morrell, analyst.

3. Cresswell's quarry, near Hollidaysburg. A. S. McCreath, analyst. (2, p. 302).

4. Manning and Lewis' quarry, near Hollidaysburg. A. S. McCreath, analyst. (2, p. 302).

5. Loop's quarry, near Hollidaysburg. A. S. McCreath, analyst. (2, p. 302).

As in other counties, the Helderberg limestones contain stone satisfactory for a variety of purposes but because of the interbedding of different kinds of good stone as well as shaly limestones of practically no value, any one intending to use any of these limestones should make careful investigations to determine whether the kind of stone desired occurs in bands of sufficient thickness to be economically workable.

ONONDAGA LIMESTONES

Some limestones are present in the Onondaga formation of Blair County, as determined by Kindle (5). In general they are of no economic importance. They are exposed about 1½ miles south of Upper Reese Station where they consist of thin limestones interbedded with shales, along the highway and railroad on the east side of Brush Run just east of Hollidaysburg and along the wagon road about 2 miles west of Canoe Creek.

CARBONIFEROUS LIMESTONES

The Carboniferous strata outcrop in the Allegheny Front along the western part of Blair County. So far as known these have been utilized only to a very small extent. Their economic importance is slight because of the steep talus-covered forested slopes where they outcrop and the near by presence of Helderberg and Cambro-Ordovocian limestones. The writer has made no field investigations of these limestones in Blair County.

Butts gave the following descriptions of the Loyalhanna (4, p. 3) and Upper Freeport (4, p. 9) limestones as he observed them in the Ebensburg quadrangle.

"Immediately overlying the Burgoon sandstone on the east side of the ravine at Allegrippus is a stratum of coarse calcareous sandstone. This stratum is marked by strong cross-bedding and a surface pitted by differential erosion, and these features give it a very distinctive appearance, by which it is recognized at widely separated points in western Pennsylvania. These characters distinguish the stratum sharply from the Burgoon sandstone below, and, as before stated, the boundary between the two is plainly apparent 10 feet above the track at the west end of the cut just east of Allegrippus station. On account of the westward dip, the limestone descends so that its top is 10 feet above the track on the west side of the ravine at Allegrippus and at track level about 100 feet farther west. It is rather more calcareous at this point than on the east side of the ravine, and this may indicate that it is more calcareous toward the top than lower down. It is closely overlain by a few feet of rock composed of thin bands of red shale and layers of gray sandstone, and these beds are in turn overlain by a considerable thickness of coarse-thick-bedded, gray sandstone.

"The stratum is universally known in the region of its occurrence as the "siliceous" limestone, though generally it is rather a calcareous sandstone. In deference to general usage it is here called a limestone and the name Loyalhanna has been applied to it, from its good development along the gorge in which that stream flows across Chestnut Ridge in Westmoreland County, and from the extensive exposures in the quarries at Long Bridge, between Latrobe and Ligonier.

"At the top of the cut immediately east of Allegrippus the thickness of the Loyalhanna limestone exposed is 40 feet. It is uncertain, however, whether this is the full thickness of the stratum, since it could not be determined whether its top is exposed at that point. It is probably not much over 40 feet thick. A small exposure of the limestone was seen on Redlick Run and bowlders of considerable size lie by the roadside on Blairs Gap Run near the mouth of the deep ravine on the north, 1 mile above the Pennsylvania Railroad bridge. It is also exposed in the road on Burgoon Run, near the northeast corner of the quadrangle."

"The Freeport limestone occurs at a few points in this quadrangle. It is about 10 feet thick in the cut at the east end of the east-bound tunnel at Gallitzin. It also occurs south of Blairs Gap, where it has been thrown out from old pits. At these points it is yellow and apparently impure. It is found in a few diamond-drill holes in the southeast corner of the quadrangle. It does not appear to be generally present, however, and probably has but little value."

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General.

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Bradford County is markedly deficient in limestones although a few calcareous beds are contained in the Chemung and Catskill rocks that underlie the surface in about three-fourths of the county. These formations consist almost entirely of sandstones and shales.

The following quotations from Sherwood and Platt's Report on Bradford County (1, pp. 37-41) contain almost the only available information concerning these limestones.

"The Burlington Limestone.* About a mile east of Burlington, on the farms of W. B. Kline, J. Morley, and C. E. Campbell, there is a bed of rock, the most remarkable I have seen in my whole district. It is a calcareous stratum forty feet in thickness—the same throughout. It is a nearly solid mass of sea-shells, which may be reckoned at millions. It must have required a very long period of time for their accumulation. In the whole forty feet exposed—and this does not seem to be its whole thickness—there is no parting of shale or other rock. The percentage of lime, which is considerable, appears to be about the same in all parts of the bed. Mr. Kline has recently commenced burning this limestone, selling the lime at the kiln for fifteen cents per bushel. It makes a gray, but very strong lime, well adapted to agricultural purposes. The facilities for quarrying the stone cannot be excelled.

"This is the thickest stratum of limestone I have ever seen in the Chemung Group, and must prove of value, as it occurs in a region destitute of lime, and where the farms would be greatly benefited by an application of this mineral manure. The bed has a considerable lateral extension through the region, for I have found it at several points east of the Susquehanna River.

"Mr. M'Creath's analysis of this limestone shows the following ingredients:

Insoluble residue, 18.010; F_2O_3, 4.428; Al_2O_3, 2.613; CaO, 41.048; MgO, 1.135; Sulphuric acid, .167; Phosphoric acid, .279; CO_2, 33.240; total, 100.920.

"About a mile and a quarter north of west from Herrick post-office, above the road and near the house of B. Carr, there are fifteen feet of reddish sandstone and bands of limy rock, dipping north. This also is a representative of Kline's limestone before mentioned. It contains fossil shells.

"The same bed is exposed again about a mile south of west from Herrick, at the forks of the road. Here it contains more lime.

"In Pike Township, at a school house, about four miles west of south from LeRoysville, there is an outcrop of limestone, which is probably the same as Kline's. Here, below the limestone, there is a bed of red shale, dipping north, ten feet or more in thickness, which may be seen near the forks of the road.

*The Burlington limestone was later called "Franklindale" by Williams and Kindle, U. S. Geol. Surv. Bull. 244, p. 95. An abandoned quarry presumably in this horizon was noted by B. Willard at Hill Top about two miles south of Rome. Pa. Top. and Geol. Survey Bull. G-4, p. 30, 1932.

"The same limestone is again exposed about two miles below LeRoysville, in the bank above the road near its forks, and not far from Dr. Cogswell's house. It appears to have considerable thickness, and may prove of value."

"A sample of the limestone, (1, p. 116) picked up in the channel of Long Valley Creek, possesses a specific gravity of 2.7054.

"It contains about 40.0 per cent carbonate of lime, 3.5 per cent peroxide of iron, 56.5 per cent argillaceous matter; total, 100.0.

"As the valley of Towanda Creek, below its junction with the Carbon Creek, presents many localities where fossiliferous limestone of lower strata than that above described, are brought into view, it was deemed proper to make also some trials to determine its degree of purity; its color is reddish gray.

"Its specific gravity is 2.658.

It yielded of carbonate of lime, 45.5 per cent; it yielded of peroxide of iron, 5.5 per cent; it yielded of earthy argillaceous matter and sand, 49.0 per cent; total, 100.0."

Other similar occurrences of calcareous strata undoubtedly are present interbedded with shales and sandstones of the county. With present transportation facilities permitting higher grade limestones and limestone products to be readily brought in to meet local demands it does not appear probable that the limestones of Bradford County at present possess any economic value.

It is of interest (1, p. 50) to know that "boulders of white limestone from central New York have been brought down the river (Susquehanna) (by glacial ice) in such abundance that lime kilns were formerly erected along the river, and canoes were used for collecting the material."

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Bucks County is poorly supplied with limestone, although it is present in three distinct areas. The Franklin limestone of pre-Cambrian age has a very limited exposure in Southampton Township. Cambro-Ordovician limestones outcrop in two areas. One occupies the valley of Durham Creek in Durham and Springfield townships, and the other underlies Buckingham Valley, extending from Furlong (Bushington) northeastward through Buckingham and Solebury Townships to the Delaware River.

At an earlier day, a number of limestone quarries were opened in these areas to supply stone for lime burning for flux and also some stone was quarried for building. In addition natural cement was made at one place as described below. Within recent years some quarries have been operated for crushed stone.

PRE-CAMBRIAN (FRANKLIN) LIMESTONE

The only place where the Franklin limestone outcrops in Bucks County has been described by F. Bascom as follows (4, pp. 4-5):

"One mile southeast of Holland and three-fourths mile west of Neshaminy River there is a very small area of limestone, which, because of its character and associations, is assigned to a pre-Cambrian horizon.

"The limestone is exposed only in the walls of an abandoned quarry, known as the Vanartsdalen quarry, which was opened about fifty years ago and was operated for thirty years. Sink holes in line with the strike of the limestone indicate that the rock underlies about 10 acres. Limestone is reported in the bed of the Neshaminy, where the new bridge for the Pennsylvania Railroad crosses that creek; this location is continuous with the strike of the quarry rock.

"The quarry rock is a coarsely crystalline marble, white when pure but usually darkened by the presence of graphite and silicate minerals. Thirty mineral species have been attributed to this locality. The most abundant of the silicates are the feldspars (orthoclase, oligoclase, and bytownite), scapolite, titanite, and phlogopite; apatite and siderite are also common. The marble is surrounded by and thoroughly injected with gabbro. To this association the rock probably owes its high degree of crystallinity. Along the contact zone augite and hornblende are abundantly developed in the calcareous rock, while calcite veins and inclusions characterize the igneous rock.

"The limestone of the Vanartsdalen quarry sustains no stratigraphic relations with any formation, and it is therefore impossible to determine with precision the horizon to which it belongs. That it is presumably pre-Cambrian is indicated by the intrusion in it of igneous material which elsewhere is confined to pre-Cambrian formations.

"In color, perfection of crystallization, and the presence of graphite and silicate minerals, the rock resembles the pre-Cambrian Franklin limestone which outcrops 70 miles to the northeast in New Jersey, and it not improbably represents a remnant of that formation left by erosion."

CAMBRO-ORDOVICIAN LIMESTONES

The Cambro-Ordovician limestone areas, although separated by more than 15 miles, are very similar. The limestones in the Buckingham Valley section have recently been differentiated and described by Bascom, Wherry, Stose, and Jonas (5). Their descriptions of the Elbrook, Conococheague, and Beekmantown (?) are quoted.

Tomstown limestone. The Tomstown limestone is the lowest limestone member in Bucks County, and has a very limited distribution. To date it has not been mapped separately, but is grouped with the Conococheague in the Durham Creek area. It is composed of massive, dense, dolomitic limestones interbedded with considerable shale and shaly limestone. Due to the large amount of shaly material at certain places, it has not been extensively worked, but in other sections the shale is much less abundant. It has yielded stone for agricultural lime, for fluxing stone, and for road metal and concrete.

Elbrook limestone. "The southeastern part of Buckingham Valley from Furlong to Lahaska station, in the Doylestown quadrangle, is underlain by limestone that is believed to be the Elbrook (5, pp. 20-21). It is deeply covered with a residual buff earthy clay soil that contains many fragments and masses of black flint and chert.

"Several quarries and road cuts expose parts of the formation. In the roadway west of Lahaska station shaly light-gray fine-grained, finely laminated limestone crops out and weathers to buff earthy platy fragments. In the quarry just north of Furlong the following beds are exposed:

Section of Elbrook limestone in quarry north of Furlong, Pa.

	Feet
Gray dolomite and hard siliceous dark limestone	10±
Finely laminated magnesian limestone and dolomite weathering to white coating; contains black flint in large irregular rough surfaced masses, some banded and mottled white, which have partly replaced the dolomite	20±
Concealed	30±
Light-blue, finely laminated earthy limestone; weathers shaly and buff; sun cracks, ripples, and other markings on bedded planes; contains scattered glassy quartz grains	15
Thick-bedded fine-grained dove-colored marble, finely laminated in part; weathers white; some blue wavy slate partings	30

"Similar thin-laminated impure limestone, which weathers shaly and contains quartz grains, is exposed in a quarry 1 mile to the northeast and also near the foot of Buckingham Mountain, 1 mile east of Buckingham post office. Along the southeast margin of the valley adjacent to Little Buckingham Mountain large masses of rough chert and hard cemented quartzite breccia in the soil suggest a probable fault. It may be that the Tomstown dolomite, which should normally occur here between the Elbrook limestone and the Hardyston quartzite, is faulted out.

"The exposures of the formation are too few to determine its thickness. Its base has not been seen and may be faulted out along its eastern margin. It dips northwest, and its top is placed just below sandy beds that form a low ridge and are classed as the base of the overlying Conococheague. The formation is estimated to be at least 500 feet thick.

"No fossils have been found in the Elbrook limestone in this area. As it underlies the Conococheague formation and has beds that are lithologically similar to the Elbrook limestone, which underlies the Conococheague in the Cumberland Valley, it is regarded as that formation. The Elbrook limestone was named from Elbrook, Franklin County, and in the type region contains fossils of Middle and Upper Cambrian age."

Conococheague limestone. "Buckingham Valley, in the southeastern part of the Doylestown quadrangle, is underlain for the most part by the Conococheague limestone. An area of the same formation is mapped in the lowland northwest of Chestnut Hill in the Quakertown quadrangle; although there are no rock exposures within that quadrangle, the Conococheague limestone is quarried in this lowland 1 mile north of the border.

"The Conococheague limestone weathers to a deep clay soil containing slabby sandstone and fragments of shale at certain horizons. It does not generally crop out in ledges but is exposed in many quarries, most of which have been abandoned. The formation comprises chiefly massive dense blue limestone and massive light-blue dolomite with thin wavy argillaceous partings and black cherty layers 1 to 1½ inches thick. The best exposure is in a quarry south of Lahaska. About 70 feet of beds there exposed consist of alternations of light-gray pure limestone containing *Cryptozoon* reefs and dark siliceous banded limestone with sandy beds, oolite, edgewise conglomerate, black chert, and small black phosphatic nodules. The alteration of beds consists of a repetition of a more or less systematic sequence about 5 feet thick, as follows: At the top, thin dark-banded siliceous limestone, weathering shaly, oolitic in places; light-gray pure limestone, *Cryptozoon*-bearing bed, about 3 feet thick; thin black siliceous limestone containing some black flint and small black phosphatic nodules in places. Repetition of a sequence of similar beds occurs in all the exposures of the formation. In quarries northeast of the area, in the Lambertville quadrangle, ripple marks are said to be a feature of this limestone. The lower part of the formation contains many beds that weather to rough yellow chert, green slaty fragments, slabby sandstone, and cherty limestone with wavy laminations like Cryptozoa. Some very sandy layers weather to slabby porous sandstone pitted by holes from which limestone pebbles have been dissolved. These harder layers, which resist erosion and form low hills in the middle of the valley, are considered the base of the formation.

"Although most of the observed dips are to the northwest, a minor sharp fold is exposed east of Lahaska, and it is probable that there are other folds which are not exposed. The thickness is therefore difficult to determine. In Chester Valley, to the southwest, the Conococheague limestone has a thickness of approximately 900 feet, and it probably has about the same thickness in the Doylestown quadrangle.

"In an abandoned quarry at Limeport, in the Lambertville quadrangle, 3 miles northeast of Aquetong, fossils were found in this formation that were determined by E. O. Ulrich to be *Solenopleura jerseyensis* (Weller) and *Lingulepis acuminata* (Conrad). These forms are referred by Ulrich to the lower part of his 'Ozarkian system' and the formation is thus regarded by him as younger than Cambrian, but it is classed as Upper Cambrian by the United States Geological Survey. This is the age also of the Conococheague limestone on Conococheague Creek, in the Cumberland Valley. The Cryptozoa found in this formation in the Doylestown quadrangle also are similar to those found in the Conococheague limestone of southern Pennsylvania. The name Conococheague limestone is therefore applied to the formation.

"*Beekmantown (?) limestone.* The limestone on the northwest side of Buckingham Valley, in the eastern part of the Doylestown quadrangle, is tentatively regarded as Beekmantown. It forms two separate areas, one between Buckingham and Holicong and the other northeast of Aquetong.

"The formation is chiefly massive-bedded fine-grained dark dolomite and light-blue magnesian limestone. It is exposed in numerous quarries adjacent to the hills of Triassic sandstone west of the valley. In an old quarry west of Holicong the limestone is fine grained and siliceous and weathers buff, earthy, and laminated, much like the limestone mapped as Elbrook. It also contains black flint, which has in part replaced the dolomite.

"The formation is estimated to be about 1,000 feet thick.

"The formation is correlated with the Beekmantown limestone largely because it lies above the Conococheague limestone and is composed of massive limestone and dolomite like the Beekmantown of the Lancaster Valley. Apparently no fossil Cryptozoa are present. The Beekmantown limestone generally contains a fauna of gastropods and other fossils of Lower Ordovician age, but none were found in this area.

"The limestones here described as Elbrook, Conococheague, and Beekmantown are a part of what was formerly called the Shenandoah limestone of Pennsylvania and Virginia. They are part of the old Auroral limestone of H. D. Rogers and of Formation No. 2 of the Second Geological Survey of Pennsylvania."

DESCRIPTION BY DISTRICTS

Buckingham Valley Area. The largest limestone area of Bucks County extends from Delaware River about two miles north of New Hope in a southwest direction to Furlong (Bushington) about three miles southeast of Doylestown. The area is about 10 miles long and averages about 1½ miles wide.

This band is surrounded by Triassic sediments and the limestones are brought to the surface by a fault with a displacement of not less than 11,000 feet. No doubt these limestones are distributed through other portions of the county, but elsewhere are deeply covered with the thick Triassic shales and sandstones.

Numerous quarries have been opened in this region for stone to be burned for lime but in recent years the local industry has greatly de-

clined. Considerable crushed stone has been made from these strata. In two places some of the limestone has been pulverized for agricultural uses or for asphalt filler.

The most northeasterly quarry in this area is a large long-abandoned opening about 2½ miles north of New Hope and a short distance west of the river road. The material is a rather impure dolomite with many shaly bands and partings. Most of the rock is thin-bedded although there are some massive beds up to 2 feet in thickness. The strata strike N.55°E. and dip 30°NW. The quarry was worked for stone for lime burning. A thickness of 40 feet was worked for a distance of about one-fourth mile. This seems to be the quarry once operated by Herbert Havens.

About 2 miles northwest of New Hope there are five small quarries within a small area. Two of these, one on either side of the road, expose low and high magnesian limestone interbedded and with some red shale partings. Edgewise conglomerate is prominent. From the one on the south side of the road, stone was once quarried to make natural cement. This operation and another earlier cement grinding plant have been described recently by Dr. B. F. Fackenthal (6) in a paper read before the Bucks County Historical Society. Quotations are as follows:

"We have records of two plants in Bucks County where natural hydraulic cement was ground for the Delaware Division canal, one at the Narrowsville locks, about four miles south of Riegelsville, the other in Solebury Township, near New Hope. These were both crude affairs.

"*Narrowsville Plant.* The limestone for the Narrowsville operation was in fact quarried in Holland Township, Hunterdon County, New Jersey, opposite Monroe (now Lehnenburg) in Bucks County, Pa., where it was burned in ordinary limekilns, the clinker loaded on Durham boats and floated down the Delaware, about three miles, to the Narrowsville gristmill, on the Pennsylvania side, in Nockamixon Township, Bucks County, then owned by Samuel Rufe, still standing, but abandoned and dismantled some years ago, where the clinker was ground on ordinary buhrstones. The water-power for this gristmill was obtained from the Delaware River, by means of a wing-wall dam.

"From an official report of H. G. Sargeant, general engineer of the Delaware Division canal, to Thomas G. Kennedy, the superintendent, under date of November 20, 1829, it appears that most of the hydraulic cement used on that canal was manufactured at the Narrowsville plant, and that they continued grinding during the season of 1830. This report is found in Hazard's Register, Vol. V, page 184, as follows:

> 'Lock No. 20 (the Narrowsville lock) would have been erected this season only that it is located directly in front of and occupies a part of the ground on which a gristmill now stands, where most of the hydraulic cement used on the line is manufactured, * * *' "

"*The Solebury Township Operation.* The other Bucks County cement operation was at the limestone quarries of Asher Ely in Solebury Township, located about two miles north of New Hope and one mile west from the Delaware River. This limestone was also calcined in ordinary limekilns and ground in a gristmill near by on the same property, located on Primrose Run, from which power was derived.

A. Limestone and coal piled up for open-heap burning. South of Frogtown, Clarion County.

B. Burning lime by the open-heap method. Near Ford City, Armstrong County.

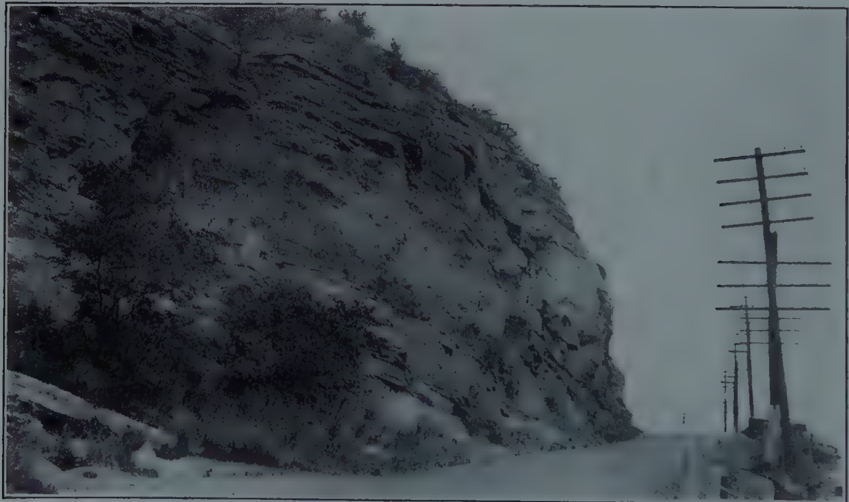
A. Vertical Helderberg strata in quarry of Enterprise Lime and Ballast Co., Hyndman, Bedford County.

B. Weathered sun cracks in Heidlerberg limestone. Quarry of Peerless Lime Co., Hyndman, Bedford County.

A. Dolomitic Beekmantown limestone, near mouth of Elk Run, Blair County.

B. St. Clair quarry of the Pittsburgh Limestone Co., Ganister, Blair County. Rodman, Lowville and Carlim limestone members.

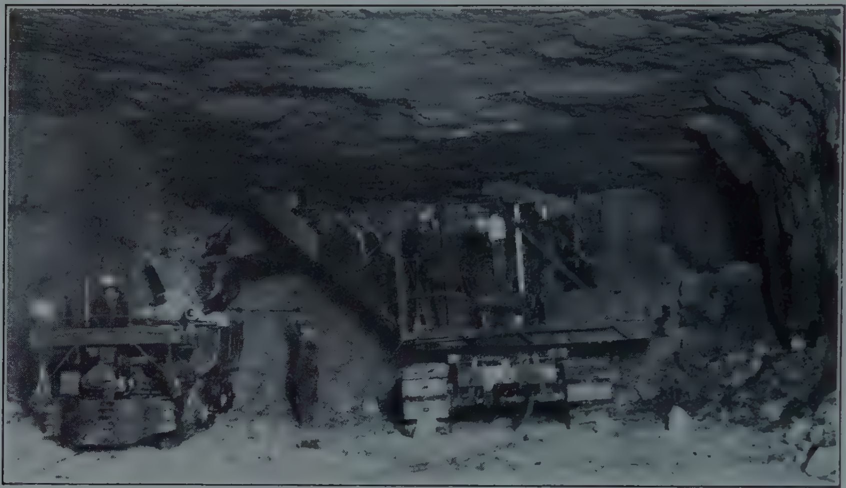
A. Foot-wall of steeply dipping Rodman limestone in old quarry on Elk Run, Blair County.



B. Shriver limestone outcropping along highway one mile east of Hollidaysburg, Blair County.

A. Entrance of Annandale mine of the Pittsburgh Limestone Co., Butler County. Vanport limestone mined is exposed in side of cut.

B. Entrance to Vanport limestone mine of Crescent Portland Cement Co., Wampum, Lawrence County.

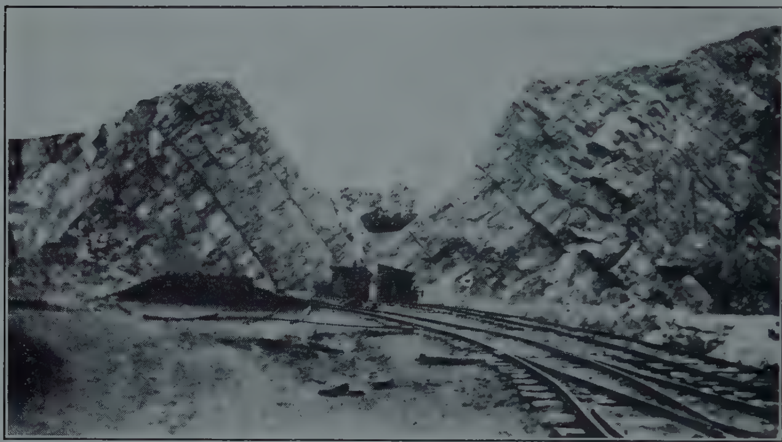


A. Loading Vanport limestone by electric shovel in Annandale mine of the Pittsburgh Limestone Co., Butler County.

B. Rainbow Falls east of East Conemaugh, Cambria County. Johnstown "cement bed" outcrops in center.

Photo. by The Mallory Studio, Bellefonte, Pa.

Mine shaft and lime plant, American Lime and Stone Co., Bellefonte, Centre County.



A. Quarry of Chemical Lime Co., Bellefonte, Centre County. Band in center most extensively worked is the high grade Bellefonte ledge.

B. Quarry of Oak Hall Lime and Stone Co., Oak Hall, Centre County.

This run discharges its water into the Delaware River at Phillips gristmill, since converted into a community house. During July, 1930, I visited these quarries, accompanied by Dr. Benjamin L. Miller, professor of geology at Lehigh University, who is studying the limestone and cement deposits of Pennsylvania for the State Geological Survey, and John F. Magee, general engineer of the Alpha Portland Cement Company; we were piloted by Warren S. Ely, who was born on the adjoining farm and knew in detail by tradition the history of cement having been manufactured there. We examined two openings from which limestone is said to have been quarried for cement; these were sampled for analyses, the result shows them to be dolomites, one of them with enough silica and alumina for making natural cement, and from that one the supply was doubtless drawn." "The old abandoned gristmill where the clinker was ground is still standing. It belongs to William L. Ely, who is operating a stone-crushing plant near by. The cement was manufactured by Asher Ely, grandfather of William, who was born on that farm July 11, 1768, (died August 12, 1855). His account books are in possession of William, and contain entries showing shipments from 1829 to 1833, mostly to contractors who built the Delaware Division canal, with its locks, culverts, aqueducts and other masonry. Thus we find shipments to Dorrance & Company, May 2, 1829, of 401 bushels of cement at 22 cents per bushel, about 60 cents per barrel; to John Van Gregory & Company, June 15, 879 bushels at the same price; to James Wallis of Bristol, August 15, 824 bushels, and on September 8, 900 bushels, both lots at 20 cents per bushel; to Lewis S. Coryell, October 22, 940 bushels; November 5, 1015 bushels, and on December 5, 192½ bushels, all at 21 cents per bushel. These shipments all in the year 1829, cover the very time when the canal was building. There are records of later shipments down to 1833, doubtless when the canal at New Hope was having the water-wheel erected to supply additional water from the Delaware River to feed the lower levels of the canal.

"On the same pages of Asher Ely's account book, are also recorded shipments of lime, showing that cement was not confused with lime. Lime was sold at 15 cents per bushel wood cost $2.75 per cord; labor 50 cents per day, and no doubt long days at that. It appears from an old letter addressed to me by the late John Ruddle, then General Supervisor of canals, that the cement used on the Delaware Division canal was not of the same good quality as that used on the Lehigh canal."

Analyses of these limestones are given in table at the close of this chapter.

A short distance to the south of the two quarries just described is the quarry of William L. Ely on the north side of a small stream, Primrose Run. The strata are almost flat. The quarry face is about 40 feet high. The stone is pulverized to pass a No. 10-mesh screen and sold for agricultural use. In 1929, about 100 tons were sold at $5.00 per ton. At an early date the stone was quarried and burned for lime. Two analyses are given on a later page.

A short distance southwest of the Ely quarry, on the north side of the road about 2 miles northwest of New Hope there is a large quarry and a near by small one that seem to have been worked long ago for building stone and for lime. The large quarry shows a face about 30

feet in height of massive gray dolomite but with some shaly laminae. The beds are regular with a strike of N.38°E. and dip 13°NW.

About 2 miles west and slightly north of New Hope and about 1½ miles north of Logan Spring there is a large abandoned quarry in the Conococheague limestone where stone was formerly obtained for burning. The exposure shows massive dolomite with some interbedded thin, shaly strata. Some of the dolomite beds are as much as 3 feet thick. Some cryptozoon fossils characteristic of the Conococheague were noted.

Just north of Logan Spring and about 2 miles west of New Hope, there are rather extensive old limestone quarries that were worked for agricultural lime. The old kilns still stand. The rock is a dense blue dolomite with some shaly material at top. About 35 feet of strata were worked. The quarry was advanced along the strike which is N.85°E. with the dip 35°NW.

A little over a mile southeast of Aquetong there are two old quarries and abandoned lime kilns, both close to the highway. The northern one shows dense blue dolomite with some interbedded black shale and shaly limestone. The strata form a part of the Conococheague limestone. The strike is roughly east-west with a dip of 25° to 30°N. The quarry with a working face about 30 feet high has been advanced along the strike about one-eighth mile. The tendency to follow the strike indicates less desirable stone, both below and above. The southern quarry at this place is largely filled with water.

To the southeast and south and within a mile of Lahaska, seven old quarries were examined. All of them have been opened in the Conococheague limestone which consists of dense, bluish dolomite with some shaly bands. On the weathered exposures some of the dolomite beds become much whiter than others so that one notes the conspicuous banded appearance so characteristic of the Conococheague formation. Cryptozoon fossils are abundant in certain layers. Mud cracks, ripple marks, and lenses of black chert were noted. In one quarry the beds strike N.42°E. and dip 21°NW. and in another they strike N.52°E. and dip 31°NW. In general the quarry faces are not more than 25 feet high. So far as known all the stone was burned for agricultural lime.

Just north of Centerville there are two very old quarries in which now only a few feet of strata are exposed. The stone is a massive dolomite in which some layers weather to a chalky white and others gray, producing the banded effect so noticeable in the Conococheague formation. Some chert lenses are present. The beds strike N.42°E. and dip 24°NW. The stone was burned for lime.

Just north of Furlong (Bushington) there is a rather large, old quarry formerly worked for lime, but in recent years for crushed stone. A section of this quarry is given in the description of the Elbrook limestone on a previous page. The beds strike N.68°E. and dip 43°NW. The shaly layers interbedded with the massive dolomite are decidedly objectionable.

During 1931 a small quarry belonging to William Stear in Buckingham Valley was worked by Hempt Bros. of Camp Hill to obtain highway stone. The output was about 150 tons daily.

Durham Creek Area. The northern area of limestones is followed by Durham Creek. The limestones appear in the east part of Spring-

town and continue to Delaware River below Riegelsville. Because of the numerous good farms in this section lime was burned at an early date in nearly a dozen localities about Springtown, Durham, and Riegelsville. During the long period when the Durham Furnace iron mines were in operation limestones in that vicinity were worked for flux. The ore was obtained from the gneiss on the south side of the limestone valley. In one of these quarries near the mouth of Durham Creek, a cave was discovered about 100 years ago in which were found a number of bones of Pleistocene mammals, several species of which no longer inhabit the region. Both for lime and for flux, the limestones in this valley are not especially good because of the rather high silica but they were used because of their proximity to the farms needing lime and to the iron furnaces. Some limestone from the region has been used for buildings and several attractive residences, barns, and bridges were constructed from this stone. In recent years a few quarries have been operated for crushed stone. For this purpose, both the Tomstown and Conococheague are well adapted except that the shaly bands must be avoided.

Dr. B. F. Fackenthal, Jr., contributes the following note on the old Durham limestone quarries. "There is a tradition that the Original Charcoal Durham Furnace, built in 1727 in the village of Durham, site since occupied by a gristmill, obtained at least part of its supply of limestone from the quarry on the south side of Durham Creek on the northern slope of Rattlesnake Hill, near the creek bridge, and opposite the dam constructed by Lewis Lillie & Son to operate their safe works. This quarry is west and south of the quarries described below. The limestone in that quarry, however, is of low grade, and it is probable that part of the supply came from quarries on the north side of the creek opposite the village of Durham, where the dolomite appears to be of much better quality."

Just east of Springtown, close to the Evangelical Church, there are two old quarries where the Tomstown dolomitic limestones were worked many years ago and the stone burned for lime. The beds dip to the southwest at low but varying angles. The stone is a hard, dense, bluish-gray dolomite with some shaly beds. The rock is greatly shattered. A similar old quarry is located about one-fourth mile to the northeast and several openings in the same limestone 1½ miles east of Springtown along the Springtown-Durham road and several others between Durham Creek and the Quakertown & Bethlehem Railroad near the northeast corner of Springfield Township. All of these were worked for stone to burn for farm use.

The only working quarry in the entire area is that of Hempt Bros. of Camp Hill, who operate quarries in other parts of the State. They work a quarry in the baked Triassic shales near Point Pleasant and in the Tomstown dolomitic limestones on the north side of the highway about half a mile east of Springtown. The quarry once furnished some building stone, but now is producing only crushed stone for the highways and general concrete work. The stone is a dense, bluish-gray dolomite in beds averaging 6 to 10 inches in thickness, with some beds a foot or more thick. The rock is very uniform for the Tomstown formation, although there is a little interbedded shaly material. Near the surface and in places at greater depth the rock is greatly shattered. The beds strike N.38°E. and dip 15°SE. The stripping averages only about 1 foot. Some vertical joints contain considerable clay but these

are few in the best part of the quarry. This clay is removed by dumping the stone on a slope grizzly on its way to the crusher. The quarry face is about 80 feet high and 200 feet long, and the capacity of the plant is 300 tons per day. The stone is loaded by steam shovel, and crushed in one roll and two jaw crushers.

Near Durham and on the left bank of Durham Creek between Durham and the Delaware River, there are several large abandoned quarries formerly worked for burning lime and for fluxing stone at the Durham iron furnaces. The ones near the northward-bending loop of the creek are in Conococheague limestone and the others in the Tomstown. In both the stone is dolomitic with some shaly bands. The strata in this section have been so greatly folded that some of them lie flat and others show folds and vertical beds. The stone in all these quarries, as shown in the analyses on a later page, is high in magnesia and fairly high in silica although varying greatly in the different beds.

TRIASSIC LIMESTONE

Two small areas of Triassic limestone conglomerate, usually called "Potomac marble," occur southeast and southwest of Springtown in the northwestern part of the county. It is doubtful whether any use can be made of the stone as it is too impure for lime, etc., and is less desirable as a decorative stone since it is not colored red as in some other localities where this type of conglomerate is developed.

A few layers of limestone interbedded with red Triassic shales are exposed in the Reading Railroad cut just south of Coopersburg.

Analyses of Bucks County limestones

All of the analyses of the Durham limestones are taken from the analysis book of Dr. B. F. Fackenthal, Jr., who was associated with the Durham Furnace plant for many years.

	1	2	3	4a	4b
$CaCO_3$	52.50	56.25	53.49	57.60	93.75
$MgCO_3$	42.11	31.91	40.32	18.16	2.21
SiO_2	3.60	6.84	5.53	16.80	2.40
Al_2O_3	0.65	2.64	-------	5.01	.60
Fe_2O_3	1.10	1.20	-------	1.71	.48

1. Quarry of William Ely, 2½ miles northwest of New Hope and 1 mile west of river road. Analysis of composite sample by Delaware River Steel Co.

2. Quarry on William Ely property, road stone. Analysis by Alpha Portland Cement Company, 1930.

3. Quarry of Herbert Havens, Limeport, 2½ miles above New Hope, along river road. Average of 10 analyses of samples taken over entire quarries and analyzed by the Delaware River Steel Co., Chester, Pa.

4. Quarry 2 miles northwest of New Hope, old cement-rock quarry. a. represents vertical section of entire face of old cement-rock quarry. b. represents one ledge of face. Analyzed by Alpha Portland Cement Co., 1930.

	5	6	7	8	9	10
SiO_2	8.65	7.99	13.65	8.84	9.49	7.01
Al_2O_3	1.83	1.32	2.35	1.68	1.80	2.75
Fe_2O_3	1.06	1.03	1.46	.86	1.10	2.01
CaO	27.15	35.21	25.45	27.62	28.86	31.49
MgO	-------	-------	-------	-------	-------	14.86
CO_2	42.21	41.14	37.98	42.32	40.92	41.09
K_2O+Na_2O	.356	-------	2.48	-------	-------	-------
P	.002	Trace	.002	.027	.01	.002
S	-------	-------	.003	.020	.012	Trace
$CaCO_3$	48.48	62.88	45.45	49.32	51.53	56.23
$MgCO_3$	39.86	25.72	34.32	39.37	34.83	31.20

	11	12	13	14	15
SiO_2	4.43	2.30	4.60	16.24	3.10
Al_2O_3	1.13	2.30	4.60	-	2.14
Fe_2O_3	1.00			-------	
CaO	28.43	30.52	29.96	--------	--------
MgO	20.87	19.71	18.66	--------	--------
CO_2	45.28	45.66	44.06	37.37	--------
K_2O+Na_2O	--------	--------	--------	--------	--------
P	.018	Trace	Trace	--------	--------
S	.09	Trace	Trace	--------	--------
$CaCO_3$	50.76	54.50	53.50	--------	57.94
$MgCO_3$	43.82	41.39	39.18	--------	42.36

5 to 9. Durham Iron works quarry. Opened by Joseph Whitaker & Company in 1848. First large quarry west of the Furnaces. Opposite Hollow Tunnel and Rattle Snake Tunnel Mines. Analysts: 5. Prof. F. W. Maynard, 1870; 6. B. F. Fackenthal, Jr., March, 1876; 7. Baron C. O. Lagerfelt, August, 1880; 8. George Auchy, August, 1885; 9. Average.

10. Durham Quarry, called "Middle Quarry," first of the above opened by Cooper & Hewitt. 1880, Matthias Lehenen, contractor. Analyst, Baron C. O. Lagerfelt, 1880.

11. Durham Quarry called "Limerick Quarry" west of last named, and nearly opposite public schoolhouse. Opened winter of 1882-83 by Cooper & Hewitt. Analyst, George Auchy, Jan., 1883.

12. Durham Cave, samples at entrance or mouth of cave. Analyst, Solomon Sjoberg, 1872.

13. Cave Hill. Southeastern point along public road near Canal locks. Analyst, Solomon Sjoberg, 1872. This cannot be a fair average sample as stone appears to be shaly and siliceous.

14. Back of Durham Furnace. Outcroppings under coal pile. Analyst, George Auchy, 1885.

15. Limestone from "Upper Quarry" of Charles Laubach, Durham, near County bridge, and near road leading from Bethlehem road to Riegelsville. Analysis by Fraunfelter (?) about 1900.

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General

6. Manufacture of Hydraulic Cement in Bucks County, by B. F. Fackenthal, Jr., 51 pp. To be included in vol. VI of the Bucks County Historical Society Papers, Riegelsville, 1931.

Limestone is found at several geological horizons in Butler County as shown in the table below, yet only one limestone is of economic importance. The Vanport, the most valuable limestone in western Pennsylvania, is well developed throughout almost all portions of the county except the southern tier of townships, where it appears only in a few places. This limestone has been worked in a small way in scores of places and on an extensive scale in several places along Slippery Rock Creek between Annandale and Branchton and along Buffalo Creek in the southeastern part of the county. The principal operations are those of the Pittsburgh Limestone Company at Annandale, the Grove City Limestone Company a few miles to the westward, and the West Penn Cement Company at West Winfield.

Generalized geologic section of Butler County

Conemaugh group
- Morgantown sandstone
- Barton coal
- *Ames (crinoidal) limestone*
- Red shales
- Bakerstown coal
- *Pine Creek limestone*
- Buffalo sandstone
- *Brush Creek limestone*
- Brush Creek coal
- Mahoning sandstone

Allegheny group
- Upper Freeport coal
- *Upper Freeport limestone*
- Upper Freeport fire clay
- Upper Freeport (Butler) sandstone
- Lower Freeport coal
- *Lower Freeport (Butler) limestone*
- Lower Freeport sandstone
- Upper Kittanning (Darlington) coal
- Middle Kittanning coal
- Lower Kittanning coal
- Kittanning fire clay
- Kittanning (Industry) sandstone and shale
- *Vanport (Ferriferous) limestone*
- Scrubgrass coal
- Clarion coal
- Fire clay
- Brookville coal

Pottsville series
- Homewood (Piedmont or Tionesta) sandstone
- Tionesta coal
- Tionesta iron shales
- *Upper Mercer, (Mahoning, Upper Wurtemburg) limestone*
- Upper Mercer coal
- Upper Mercer iron shales
- *Lower Mercer (Lower Wurtemburg) limestone*
- Lower Mercer coal
- Lower Mercer iron shales
- Upper Connoquenessing sandstone

It should be understood that the section names only the principal members, omitting many sandstone beds and most of the shales that collectively constitute the larger portion of the strata of the county. Practically every one of the members mentioned is more or less continuous so that any one may be missing at a certain place even though the underlying and overlying beds are present. The strata have been thrown into gentle folds that have a general trend northeast-southwest and in addition there is a definite dip of the folds to the southwest. This latter results in the distribution of the geological series. The Pottsville series appears at the surface principally in the valley of Slippery Rock Creek but to a lesser extent along a few small stream valleys in the northeastern corner of the county. Elsewhere the Pottsville strata are concealed from view by the overlying beds but presumably they underlie the entire county.

The members of the Allegheny group constitute the surface rocks over the northern third of the county and in addition along all the

principal streams with the exception of those noted for the Pottsville outcrops. Strata of the Conemaugh group constitute the uplands over the central and southern portions of the county.

LIMESTONES OF THE POTTSVILLE SERIES

Information is lacking concerning the Lower and Upper Mercer limestones of Butler County. In Mercer and Lawrence counties these two limestones are of some local importance although they are always

Fig. 6. Limestone areas in Butler County.

1. West Penn Cement Co.
2. Annandale mine of Pittsburgh Limestone Co.
3. Grove City Limestone Co.
4. Mercer Lime and Stone Co.
5. Harrisville quarry of Pittsburgh Limestone Co.
6. Wick Lime Co.
7. Western Pennsylvania Syndicate Co.

rather thin, ranging from 2 to 4 feet, and vary in quality from poor to fair. No place is known where either of these beds has been utilized in Butler County, although it is not improbable that during the period when small agricultural lime operations were abundant throughout the State, some stone from these two limestone members

might have been quarried along Slippery Rock Creek and along the small tributary streams of Allegheny River in the northeastern part of the county.

VANPORT LIMESTONE

The descriptions that follow are taken partly from the author's field notes and partly from notes by C. R. Fettke and E. G. Hill, who in 1919 collected much information concerning road-making materials for the State Highway Department. It should be kept in mind that part of the material following is therefore not up to date in some respects, although in general correct. For lack of time the entire county was not re-studied by the author.

The Vanport limestone of Butler County is a typically marine fossiliferous limestone, usually bluish-gray in color, varying light or dark, ranging in thickness from 0 to 25 feet, and is present in the greater part of the county. Changes in thickness, due probably to erosion or to original differences in deposition, occur rapidly in some localities. At one point a thickness of 18 feet appeared to be entirely lost within 1½ miles. Occasionally sandstone is found resting directly upon the limestone, indicating the possibility of some erosion after the limestone was laid down and subsequent to the formation of the usual overlying strata.

Vanport limestone beds are usually separated by irregular approximately horizontal bedding planes from ½ inch to 2½ inches and more apart, along which the rock readily parts. Stylolitic structures also frequently show on the rock faces. Vertical joints at intervals of several feet are usually found running in two sets at opposite directions to each other. Physical tests show a medium coefficient of wear, medium hardness, low toughness, and good cementing value.

Chemically, the rock contains from 86 to 96 per cent calcium carbonate, less than 2 per cent magnesium carbonate, and siliceous matter from 2 to 6 per cent. Different layers vary slightly in chemical composition. In making this study, special attention was given: 1. To general location of outcrop. 2. To open quarries or mines now being operated. 3. To open quarries not now in operation. 4. Available sites for new quarries.

Outcrops of the Vanport appear along the slopes of many stream valleys but exposures showing the full thickness are rare. The exposed faces are rugged and broken, the horizontal and vertical joints widened by the action of percolating waters through the mantle of residual soil usually found as a cover. Most of the Vanport is underlain by impervious beds of shale, and surface waters penetrating the limestone through its vertical joints find outlets in numerous springs. These springs assist the prospector in locating the outcrops.

Outcrops of the Vanport appear in Winfield Township along Rough Run and Buffalo Creek over a restricted area, which was one time extensively mined by the Pittsburgh Limestone Company and is now being mined by the West Penn Cement Company. The strata here are about 22 to 25 feet in thickness. Going northward and westward, outcrops are next encountered in Muddy Creek Valley, Muddy Creek Township, extending eastward from the Lawrence County line and northward into Worth Township. Quarries have been operated in this district on faces from 15 to 21 feet thick, and the indications

are that the limestone is at least 15 feet high over the entire area. At some points the formation is so deeply covered by glacial deposits that quarry sites are poor.

The limestone also crops in the Slippery Rock Valley, near the line between Butler, Lawrence, and Mercer counties, extending from the vicinity of Jacksville in Worth Township northward to the junction of Slippery Rock and Wolf creeks, thence eastward along Slippery Rock Creek and its tributaries into Slippery Rock and Brady townships, then northward along Wolf Creek through Slippery Rock Township into Lawrence County. The stone in these localities has not been extensively quarried or mined. Small quarries on the farms and the history of wells in the neighborhood indicate a thickness of the formation varying from 10 to 18 feet. At the northern end of the area, across the county line in Lawrence County, large quarries were opened on faces from 15 to 18 feet thick but they have not been worked for a number of years.

Travelling eastward from the junction of Wolf and Slippery Rock creeks through Slippery Rock, Brady, and Marion townships, and into Cherry Township along the valley of Slippery Rock Creek and its tributaries, Hogue, Glade, Big, McDonald, Findlay, and McMurray runs, South Branch, North Branch, Black Creek, and Seaton Creek, the limestone is found in many places outcropping in the steep-sided valleys of the streams. Exposures show a thickness of 9 to 17 feet.

In two large open quarries along McDonald Run the faces are from 12 to 18 feet thick under a shale and clay cover from 20 to 26 feet deep. Along McMurray Run a large quarry is operating on a face from 13 to 18 feet thick, and 1¼ miles north of the quarry, the rock is being mined under about 41 feet of cover.

In the fork of Slippery Rock and Black Creeks, east of Black Creek and north of Slippery Rock Creek, the limestone has been extensively quarried on a face 1,400 feet long and from 14 to 18 feet thick.

On the east side of the district in the valleys of the tributaries of Allegheny River, the most southern outcroppings appear along Bear Creek and its tributaries, South Branch, Middle Branch, and North Branch, in Parker and Allegheny townships. The principal outcrops are just west and northwest of Parkers Landing, on the properties of R. G. Morgan, Evan Griffith, and the Fox Estate. The beds in this vicinity show a thickness of about 10 feet or less, and there are no evidences of any extensive quarrying.

Farther north, in Venango and Allegheny townships, a number of outcrops appear, but probably nowhere does the bed exceed 10 feet in thickness except at a point one mile north of Anderson Stone House where a thickness of 15 feet was measured. There is no evidence of extensive quarrying in this locality.

QUARRIES IN OPERATION

The Pittsburgh Limestone Company operates a large limestone mine at Annandale with a capacity of about 3,700 tons per day. The section is as follows:

Section of Vanport limestone, Annandale, Butler County

	Ft.	*in.*
Shale		
Limestone, gray	3	0

Parting, rock taken to this point at times		
Limestone, gray	2	0
Parting, rock usually taken to this point		
Limestone showing banding	3	0
Parting		
Gray stone, best grade	4	0
Parting		
Limestone, gray	3	0
Parting		
Bluish limestone	2	8
Parting		
Bluish limestone, left for floor	1	4
Fire clay	1	4
Coal		1 to 2

As shown above, the limestone is 19 feet thick at this point although it has some variation. Of this, 12 feet 8 inches is usually removed although occasionally the overlying 2-foot bed is also mined.

In mining the stone the entries are driven 30 feet wide and with 30-foot pillars. The rooms are 40 feet wide with 20-foot ribs. The broken stone is loaded by air and electric shovels and hauled outside to the crushing plant by gasoline locomotives. Very little secondary shooting is required. A little timber is needed near the outcrop but none farther back in the hill. Forced ventilation is required and brattices are put up to close passages and worked-out rooms. Eventually the mine will extend a few miles from the portal. The stone goes to a gyratory crusher where it is broken to 8 inches and then sized by screening. Everything less than ¾-inch size is sent to the Universal Atlas Cement Company near Pittsburgh for the manufacture of Portland cement or stored when not needed. The balance is shipped to the Pittsburgh furnaces for flux. Crushed stone for ballast is also made at times and broken to meet specifications. The company has large holdings, comfortable office, residences for employees, playgrounds, and other equipment.

The Grove City Limestone Company operates a mine at Osbornes, a station on the Hilliards Branch of B. & L. E. Railroad about half a mile east of Nelsons Bridge. At one time the company worked an open quarry but with the increase of required stripping the ledge was followed into the hill by underground mining. The Vanport at this point is generally about 16 feet thick but in places is as much as 18 feet. It is a rather uniform gray stone except in the lower part where it is more bluish. In mining 12 feet of stone is removed, leaving 4 feet at the top for a roof. The entries are 30 feet wide with the rooms 35 feet and occasionally 45 feet. There are several rolls in the stone with dips of several degrees. In one of the sags considerable water came through the roof, necessitating pumping. Some filling has had to be done in these troughs after removing the stone in order to maintain the grade.

The upper layers of stone left for the roof, where exposed in the old open quarry, are seen to contain numerous fossils, particularly very large crinoid stems as well as cup corals and echinoid spines. The "buhrstone" iron ore layer so commonly noted immediately overlying the Vanport in western Pennsylvania is well developed. It is a foot thick.

At one time the stone at this place was burned for lime but the kilns have been sold. It was also once sold for flux and Portland

cement but more recently it has been marketed mainly as crushed stone and to a lesser extent as pulverized agricultural limestone. The stone is washed although at present this is scarcely necessary. The washing was started when open-cut quarrying was carried on and considerable clay became mixed with the stone. It was also necessary when the stone mined was near the outcrop with thin cover and many cracks containing clay. These are no longer encountered as the cover has increased with the extension of the workings into the hillside. The agricultural stone is dried in a rotary drier and then pulverized to pass through a 20-mesh screen. It is only produced during the season when it is used by the farmers. The capacity of the plant is 800 tons of crushed stone per day. An analysis of the stone is given on a later page.

The Mercer Lime and Stone Company, Branchton, formerly the Branchton Limestone and Ballast Company, has a quarry and mine about half a mile northeast of Branchton. The stone was removed by open cut quarrying over an extensive area estimated to be about 25 acres. When the workings had been extended to a point where the shale overburden amounted to 30 to 40 feet, the company largely changed to underground mining. The drifts have not been driven very far back into the hill and when visited in 1929, no stone was being removed underground and only a limited amount by open cut quarrying. The stone was all being burned in 4 upright kilns for agricultural lime. The Vanport at this point is similar to that of Osbornes and Annandale. It is about 18 feet thick.

The Pittsburgh Limestone Company, Harrisville, was operating a large quarry and also a mine, in 1919, about one mile east of Harrisville Station. The Vanport there is 15 feet thick. The quarry face was 1674 feet long. The quarry was then producing 250 tons of stone per day and the mine 400 to 500 tons. The stone was used for flux and Portland cement.

The Wick Lime Company, Wick, formerly the Climax Limestone Company, has a large quarry along McDonald Run at Wick. In 1919, the quarry face was 1176 feet long. In recent years the quarry has been worked on a small scale and some underground mining has been done. The Vanport here varies from 13 to 17 feet in thickness.

Western Pennsylvania Syndicate Company once opened a quarry in the Vanport at Stonehouse, about 3 miles north of Bruin, but apparently did not take out much stone. In that vicinity many farmers have dug stone in small quantities and burned it to lime by heap roasting, 20 to 25 tons of stone at a time.

Fettke and Hill reported in 1919 a small quarry operation about 1¼ miles south of Jacksville in Worth Township. The Vanport there is 17 feet thick and a large amount of stone could be obtained.

The West Penn Cement Company, West Winfield. One of the largest limestone operations in Butler County is that of the West Penn Cement Company at West Winfield, where the Vanport limestone is being extensively mined. This is the first place where limestone was mined in Pennsylvania and the second oldest limestone mining operation in the country. The earliest record of limestone mining in the United States is at Lowmoor, Virginia, in 1883. The West Winfield

mine was started in 1894 and has been in operation ever since. It has been worked to supply limestone for flux, for lime, and more recently for Portland cement manufacture. Not only has limestone been worked at this point, but also coal, shale, and sandstone. The limestone, shale, and coal are used by the cement company and the sandstone was used by the glass companies as an abrasive. A short distance away the fire clay beneath the Clarion coal is thicker than at this point and is mined and used in the manufacture of tile.

The section exposed in the hill between Rough Run and Long Run is approximately as given below. The thicknesses vary considerably in different parts of the hill, and in addition, the upper six members have been in part or entirely removed by erosion in places.

Average geological section at West Winfield

	Thickness Ft.	in.
Mixed shale and sandstone	50	
Lower Freeport coal	2	
Fire clay	4	
Mixed shale and sandstone	53	
Upper Kittaning coal		6
Fire clay	2	6
Shale and sandstone	50	
Middle Kittanning coal	1	6
Fire clay	2	6
Shale and sandstone	50	
Lower Kittanning coal	3	
Fire clay	4	
Shale and sandstone	40	
Iron ore	1	6
Vanport limestone, mined	25	
Gray limestone, left as roof of mine 3′		
Shale parting		
Thin-bedded limestone, ("shell rock"), drilled and shot down after removal of underlying massive limestone ..... 2′		
Gray limestone, uniform in character 13′-15′		
Shale parting		
Bluish to black limestone .... 4′- 5′		
Shale, for cement, mined	16	
Clarion coal, mined at times	3	6
Fire clay and shale	16	
Clarion sandstone, mined	50	
Shale	15	
So-called "70 ft." sandstone		

The beds are nearly horizontal except in a belt that crosses the property in a general east-west direction and is approximately 2000 feet in width. Within this band there is a perfect jumble of blocks of coal, shale, sandstone, and limestone folded and faulted in every conceivable manner. In one place a thickness of 5 feet of Vanport limestone was seen standing on edge with practically a vertical dip. The cement company has driven a drift through this disturbed area and is mining stone on both sides. This complicated structure appears to be due to the removal in large part of the limestone bed by underground solution and the subsequent collapse of the roof. Locally this band has been called an "erosion."

The following paragraphs (16) describe some of the methods and equipment in 1929.

"The mine consists of tunnels, 25 ft, wide, from which rooms open alternately on both sides, on 60-ft. centers. The rooms are 35 ft. wide, an average of 20 ft. high, and the pillars, 25 ft. wide. Drilling is done by hammer drills, on tripods, by the breast-stoping method. The drilling equipment consists of 8 Gardner-Denver drifters; 3 Gilman drifters; 1 Chicago Pneumatic drifter; 2 Gardner-Denver and 1 Ingersoll-Rand stopers and 3 Ingersoll-Rand, 1 Chicago Pneumatic and 1 Gardner-Denver block-hole drills. Drill sharpening equipment includes a Model 8 Gardner-Denver drill sharpener on which is mounted a Model 10 hole-puncher. All the drills are fitted with LO-3A Gardner-Denver line oilers. Round 1¼-in. hollow drill steel is used and a set of six lengths will drill an average of three 12-ft. holes. The average drilling speed is 5 in. per minute.

Loading and haulage equipment consists of a Marion Type 7, all electric, 1-yd. shovel, on crawler treads; a Marion Type 450, all electric shovel, with crawler treads and 1¼-yd. bucket; a ⅝-yd. Thew shovel on crawler treads and 3 Butler air shovels with ¼-yd. buckets, operating on rails. The latter are used for auxiliary loading, cleaning up, etc.

"The cars, of which there are 75, are of a special design, built to West Penn's own specifications. They are of 135 cu. ft. capacity, are of steel and wood construction, and are equipped with Hyatt roller bearings and Alemite lubrication system. They are fitted with swivel couplings and 4-wheel, band-type brakes with take-ups. Fifty of the cars were built and furnished by the Hockensmith Wheel and Mine Car Co.; the remainder by the American Car and Foundry Co. Three 7-ton Ironton, double-motored trolley locomotives take care of the haulage between the mine and crushing plant.

"Power, purchased from the West Penn Power Co., is received at the mine at 2300 volts. A General Electric 150-kw. motor generator set converts the power to direct current at 220 volts for serving the locomotives, shovels, fans and lighting system. Air for the small shovels and drilling is supplied by a 1350 cu. ft. capacity Bury compressor, direct-driven by a 225-hp. General-Electric synchronous motor. Due to recent additional air requirements a second compressor of the same size and make has been ordered and will be installed at an early date.

"Considerable storage space is provided for loaded mine cars above the plant. The locomotives bring out trains of six or seven cars each and "spot" them on either of two storage tracks. From there cars are pulled down to the crusher, a train at a time, by a home-made car-puller, consisting of a Mead-Morrison hoist and a series of sheaves arranged between the tracks. A car at a time is spotted on a Roberts and Schaeffer rotary car dumper; and as a train is dumped it is "dropped" to the "empty" track below the crusher where a locomotive picks it up and returns to the mine through an entrance other than that from which it came out with loaded cars. This dumping and haulage system provides for cars and locomotives always moving in one direction.

"The initial crusher is a 30-in. Traylor "Bulldog" belt-driven by a 150-hp. Allis-Chalmers motor. It is set to discharge at 4 in. and its product flows by gravity to a Stephens-Adamson live-roll grizzly with 2¾-in. openings. The oversize is elevated in a 24-in. Jeffrey chain-bucket elevator, driven by a 10-hp. motor through a James

speed reducer. The elevator empties into a 10-in. "Bulldog" crusher, set to discharge at 2 in. The product of this crusher and that of the grizzly are moved by belt conveyor to the screening plant. The conveyor is of 325 ft. centers, 24 in. wide, is mounted on Robins, Hyatt, roller-bearing equipped idlers, with Alemite lubrication, and is driven by a 20-hp. motor.

"The revolving screen is 72 in. in diameter, 26 ft. long and has two jackets. There are four sections to the main shell; the first three sections have 2¾-in. openings and the last one has 3½-in. openings. The first jacket is 17 ft. long, 15 ft. of which has 2-in. openings; the other 2 ft., 1½-in. The outer jacket is 15 ft. long and has ⅝-in. square holes its full length. The product of the outer jacket (minus ⅝ in.) is chuted to a 12-in. screw conveyor, 20 ft. long, which discharges through hand-operated gates to three 3- x 8-ft. Universal vibrating screens, each driven by a 3-hp. motor. These screens are fitted with ⅜-in. mesh cloth. The oversize from them is sold, for the most part, for road dressing, and the undersize, known as "buck-wheat" is sold for the manufacture of concrete products.

"The material passing through the 2-in. screen is chuted to a fourth Universal vibrating screen where any number of special sizes are made.

"There are two rows of concrete bins, six in each row, directly under the screens, the combined capacity of which is 1800 tons. The arrangement provides for loading a car on each side of two tracks simultaneously, while motor trucks can be loaded from side chutes.

"The cement plant uses the minus 2¾-in. stone, which is loaded into the company's bottom-dump cars and hauled, about 1/5 mile, to the cement plant. The conveyor belt from the crushing plant to the screening plant is so arranged that it can discharge directly into the bins for shipment to the cement plant, without screening. Recently two additional vibrating screen washers have been installed to wash all sizes of stone before shipping. These washers are for removing stone dust only, as the stone is already cleaned of clay or soil."

The capacity of the cement plant is 5000 barrels per day. The amount of ballast stone made depends upon the demand.

The Pittsburgh Limestone Company formerly operated two limestone mines on leased property, one on either side of Rough Run. These farms are now owned by the West Penn Cement Company. The limestone in these properties is closely similar to that described above.

The shale associated with the limestone has been used in the manufacture of Portland cement. Three shale analyses are given.

Analyses of shales at West Winfield

	1	2	3
SiO_2	57.36	41.00	49.36
Al_2O_3	22.28	19.22	21.67
Fe_2O_3	9.48	19.62	5.85
CaO	2.19	2.03	1.23
Loss	8.78	11.96	13.20
Total	100.09	93.83	91.31

1. Shale from cross cut through so-called "erosion" belt.
2. Shale overlying limestone
3. Shale underlying limestone (between stone and coal)

QUARRIES NOT IN OPERATION

Additional notes by C. R. Fettke and E. G. Hill (taken in 1919).

Muddy Creek Township. 1. Quarry of the Lehigh Portland Cement Co. About one mile south of Paynes on a tributary of Muddy Creek there is an extensive quarry formerly operated for flux and for Portland Cement. It is connected with the Lake Erie & Bessemer Railroad by a spur. In the quarry which was worked on both sides of a narrow ravine, the Vanport shows a thickness of 15 to 18 feet. The face was advanced under an increasing depth of overburden. The stone is rather badly weathered and breaks into gnarly masses. Numerous loose fossils freed by the solution of the matrix were observed. The iron ore layer overlying the limestone is shown in several places with a maximum thickness of 8 inches. Analyses of the stone are given on a later page.

2. Quarry of Pittsburgh Limestone Company. At Porterville Station. Average thickness of face 14.7 feet. Present length of face 400 feet but can be greatly extended; cover about 24 feet; available quantity 1,800,000 tons. Transportation facilities, siding on western Allegheny branch of the B. & L. E. Railroad at Portersville Station.

Worth Township. 3. Quarry of Clyde Rennick on west bank of Slippery Rock Creek, half a mile north of Kelly's Bridge. Thickness of face 15 feet or more; cover 10 to 19 feet; quantity undetermined. Transportation facilities, road haul three-fourths of a mile to county road and two miles to State highway.

4. Quarry on farms of J. B. Studebaker and G. F. Gardner, east of Eight Square School. Thickness of face, 15 feet; cover very light; available quantity 1,320,000 tons. Transportation facilities, one mile haul to State highway at Elliott's Mill over a good dirt road.

Brady Township. 5. On south side of Hogue Run one-third of a mile west of West Liberty, on the property of S. S. Hogue. Thickness of face 16 feet; cover 11 to 30 feet over an area 1000 by 100 feet; available quantity 135,000 tons; transportation facilities, available only for local improvements.

6. Quarry of C. E. Smith, three-fifths of a mile north of Halliday School. Thickness of face 14.7 feet; cover 7 to 20 feet over an area 2000 feet by 100 feet. Available quantity 250,000 tons. Transportation facilities, one mile haul to Butler-Slippery Rock State highway near Stone House.

7. Quarry of Jacob Snyder and Sullivan Estate, on the opposite of Big Run from the C. E. Smith quarry. Thickness of face 11 feet; cover light, in some places not exceeding five feet. Available quantity 1,500,000 tons. Transportation facilities, one mile easy haul to Butler-Slippery Rock State highway.

Slippery Rock Township. 8. Quarry of Ringard Graham on west side of Wolfs Creek, 1¾ miles west of Slippery Rock village. Thickness of face 16 feet; cover not exceeding 30 feet; available quantity 1,750,000 tons; transportation facilities poor, two mile haul to Slippery Rock.

9. Quarry of G. W. Heinz on east side of Wolf Creek, 1½ miles west of Slippery Rock village. Thickness of face 16 feet; cover not ex-

cessive. Available quantity 500,000 tons. Transportation facilities 1½ mile haul to Slippery Rock.

10. Quarry of David Dickey on north side of Slippery Rock Creek in southwest corner of township. Thickness of face 16 feet; cover from 0 to 30 feet; available quantity 100,000 tons. Transportation facilities, 1¼ mile haul to Slippery Rock-New Castle State highway.

11. Quarry of Samuel Walker half a mile southwest of Doughertys Mills. Thickness of face 12 feet; cover on an area 700 feet by 100 feet extending into land of J. B. Demil, from zero to 12 feet. Available quantity 70,000 tons. Transportation facilities, two mile haul to State highway.

12. Quarry of John Sanderson half a mile southeast of Doughertys Mills. Thickness of face 11 feet; available quantity 250,000 tons. Transportation facilities, this quarry is on the Butler-Slippery Rock State highway.

13. Quarry on properties of Sylvester Kelley and Shafer Keister, on opposite sides of Coaltown Road east of Keisters. Face 9 to 16 feet; cover zero to 30 feet. Available quantity 900,000 tons. Transportation facilities, short haul to Keisters Station, on the B. & L. E. Railroad. One mile of siding on the existing grade would reach the quarries.

14. Quarry of Henry Wilson, on Branchton-Slippery Rock Road midway between the two places. Thickness of face 8 feet or more. Available quantity on area 1500 feet by 100 feet, 100,000 tons. Transportation facilities, 1½ mile haul to State highway.

15. Quarry of W. W. Dougherty on the north side of Slippery Rock Creek near Maniteau. Thickness of face 18 feet; quarry face one mile long, can be developed and carried back for 100 feet or more without excessive cover. Transportation facilities lacking at present.

Parker Township 16. Quarry of Edwin Griffith, immediately west of Parkers Landing. Thickness of face 10.8 feet. Present face of 70 feet can be extended in length. Entire cover from 8 to 24 feet. Available quantity 300,000 tons. Transportation facilities, short haul to Parkers Landing or about one mile across the river to the Pennsylvania Railroad.

17. Quarry of William Parker one mile north of Parkers Landing. Thickness of face 10 feet; present length of face 110 feet which can be extended over entire knoll without extensive stripping. Available quantity 600,000 tons. Transportation facilities, one mile haul to Parkers Landing or to the Pennsylvania Railroad.

18. Quarry of R. B. Thomas 1½ miles west of Parkers Landing on the road along the north branch of Bear Creek. Thickness of face 12 feet and cover can be stripped for a few yards. Available quantity uncertain. Suitable only for local roads.

Mercer Township. 19. Quarry of George Searing just south of Harrisville. Thickness of face 10 feet. Cover can be stripped on an area 1000 by 500 feet. Available quantity 400,000 tons. Transportation facilities on the Pittsburgh-Franklin highway two mile haul to B. & L. E. Railroad.

Marion Township. 20. Quarry of Joseph Duffy northwest of Atwell's Crossing. Thickness of face 16 feet; present quarry face can be extended 3000 feet around brow of hill; entire cover from 8 to 16 feet. Available quantity 600,000 tons. Transportation facilities, none at present. A siding from Hilliard's Branch on the B. & L. E. Railroad, ¼ mile long involving a span across Slippery Rock Creek, and a gravity plane 750 feet long would be necessary.

AVAILABLE SITES FOR NEW QUARRIES

Muddy Creek Township. 1. South side of Muddy Creek at Portersville Station. Face 12 feet or more in thickness. Transportation facilities, Western Allegheny Branch of the B. & L. E. Railroad.

Worth Township. 2. Three-fourths of a mile north of Portersville Station between the road running north and the creek on the east. Bed for a distance of one mile may be uncovered, under cover of 30 feet or less. Available quantity 6,500,000 tons. Transportation facilities, siding may readily be constructed to Portersville Station, Western Allegheny Branch of the B. & L. E. Railroad.

3. On south side of Slippery Rock Creek near first bridge above confluence with Wolf Creek. Face 9.5 feet and over; cover 5 to 10 feet. Available quantity 34,700 tons or more. Transportation facilities, ¼ mile haul to Slippery Rock-New Castle State highway.

4. One-fourth of a mile east of Jacksonville-Moores Corner road on farm of George Weimer. Face 15 feet; cover 0 to 13 feet. Available quantity 380,000 tons. Transportation facilities ¾ mile haul to Slippery Rock-New Castle State highway.

5. Near the Weimer farm on property of H. Shields. Face possibly 18 feet; cover slight. Available quantity 500,000 tons. Transportation facilities ¾ mile haul to Slippery Rock-New Castle State highway.

6. On Slippery Rock-New Castle State highway just west of Moore's Corners. Face 10 feet or more; cover 0 to 20 feet.

Clay Township. 7. Half a mile north of Hallston on property of W. Thomas. Face, not measured; cover thin over a large area. A few rods from main line of B. & L. E. Railroad. Area should be prospected for definite figures.

Slippery Rock Township. 8. One and one-half miles east of the confluence of Wolf and Slippery Rock Creeks, on north side of Slippery Rock Creek on property of W. E. Robinson. Thickness of face 16 feet; cover not exceeding 12 feet. Available quantity 134,000 tons. Transportation facilities, 1½ mile haul to Slippery Rock-New Castle State highway.

Note: Good quarry sites might be found at a number of places eastward and north of Slippery Rock Creek for a distance of three miles or more to quarry of Samuel Walker. Transportation facilities, however, are poor unless operations would be sufficiently extensive to justify the construction of a siding 1¾ miles long with a bridge over the creek. A vast tonnage would be available in this district on faces probably averaging 18 feet.

9. One-third of a mile northwest of Dougherty's Mills on either side of road. Thickness of face 20 feet; cover 0 to 11 feet on one side

and 0 to 16½ feet on the other. Available quantity 300,000 tons. Transportation facilities, on the Butler-Slippery Rock State highway.

10. Near Adams Corners south of quarry of Climax Lime and Stone Company, along north side of run. Thickness of face 14 feet; cover not excessive on area 2000 feet by 250 feet. Available quantity 600,000 tons. Transportation facilities, siding one-fourth mile long should be built to the B. & L. E. Railroad, at Wick.

Cherry Township. 11. On west side of McMurrays Run between quarry of Branchton Limestone and Ballast Company on the south and quarry of the Pittsburgh Limestone Company on the north. Face 15 feet with cover 0 to 30 feet on an area 4000 feet by 200 feet. Available quantity 1,000,000 tons. Transportation facilities, quarry might be worked in connection with adjoining quarries which have crushing plants and shipping facilities.

12. A short distance south of Atwells Crossing on farm of M. A. Thompson, at an elevation of 110 feet above railroad grade. Face 15 feet with cover not excessive on an area 9000 feet by 200 feet. Available quantity 2,250,000 tons. Transportation facilities, a self-acting incline plane 600 feet long should be constructed to short siding on the B. & L. E. Railroad.

13. One mile southeast of Bovard on properties of Joseph Hamilton, C. J. Simpson and the Grossman Heirs et al. Face 15 to 18 feet; cover thin at outcrop but increases rapidly up the slopes. Face may be extended for about one mile. Transportation facilities, an abandoned branch line of the railroad passes the site, which, if relaid, would make this quarry accessible.

14. East of Rye Bread School. Thickness of face 18 feet. A face of nearly two miles can be opened around a knoll which can be completely stripped. Available quantity very large. Transportation facilities none, unless siding be constructed on an old grade from Branchton on the B. & L. E. Railroad, or product carried through gap to site near Atwells Crossing referred to as No. 12.

15. One mile north of Moniteau on west side of road from Moniteau to Atwell's Crossing. Face 18 feet; cover 0 to 30 feet. Available quantity 2,000,000 tons. Transportation facilities poor at present; not near any railroad or State highway.

Parker Township. 16. Two miles southwest of Parkers Landing on road to Bruin. Face 6 feet, cover light. Available quantity 25,000 tons. Transportation facilities poor; available only for local improvements.

Mercer Township. 17. East of Harrisville, between the east and west forks of McMurray Run, extending into Marion Township. Thickness of face 15 to 20 feet. Cover thin over a large area. This site seems favorable for large quarrying operations, with 10,000,000 tons available. In order to afford adequate transportation facilities, a spur from the B. & L. E. Railroad 2¼ miles long would be necessary. No excessive grading would be required.

Marion Township. 18. North of Atwells Crossing on property of S. J. Black. Thickness of face 10.8 feet. A face 750 feet long can be

worked back from outcrop 200 feet without excessive cover. Available quantity 200,000 tons. Transportation facilities, road haul about one mile to Atwells Crossing, on Hilliards Branch of the B. & L. E. Railroad.

19. Two and one-half miles west of Murrinsville on road to Harrisville on the farm of R. Gillquist. Thickness of face 16 feet; cover light. Available quantity 200,000 tons. Transportation facilities good for local roads only.

Venango Township. 20. Small quarry sites can be developed in this township for local highways. The formation is thin in most places, seldom exceeding 10 feet. It is thickest in the northeastern part of the township along the headwaters of Little Scrubgrass Creek.

Analyses of Vanport limestone from Butler County

	1	2
$CaCO_3$	93.61	94.89
$MgCO_3$	2.33	1.50
SiO_2	2.20	1.48
Al_2O_3	1.44	1.00
Fe_2O_3	.54	.72
P	.029	

	3	4	5	6	7
SiO_2	1.64	4.40	7.40	12.94	1.38
Al_2O_3-Fe_2O_3	2.20	4.38	5.58	11.00	1.90
CaO	53.62	50.26	47.93	39.91	53.52
MgO	.86	.86	.84	1.20	.64
CO_2-H_2O	42.30	40.24	38.50	32.10	42.38
$CaCO_3$	95.76	89.64	85.58	71.26	95.57
$MgCO_3$	1.82	1.82	1.77	2.51	1.34

1. Grove City Limestone Company's quarry at Osbornes. Analysis by Pittsburgh Testing Laboratory.
2. Average of 270,000 tons of stone from the Annandale mine of the Pittsburgh Limestone Company in 1920. Furnished by the company.
3-7. Different grades of stone from Payne quarry of Lehigh Portland Cement Company, 1 mile south of Paynes Station. Analyses furnished by company.

FREEPORT LIMESTONES

Lower Freeport limestone. The Lower Freeport limestone, formerly called the Butler, lies a short distance below the Lower Freeport coal and has been recognized in many places in the southern half of the county. It ranges from 2 to 5 feet in thickness, is everywhere impure, with high iron and argillaceous matter, and is practically useless. Many years ago it was dug in small amounts and burned for agricultural lime in a few places.

The Lower Freeport is perhaps thickest in Winfield Township where White described it (2, p. 94) as "quite ferruginous, has a buff cast, is much brecciated, and nodules of iron ore are disseminated through it. It is called the 'bastard limestone' by the inhabitants as from impurities of iron and earthy matters it will not slack on burning."

Along Connoquenessing Creek in Forward Township it is 3 feet thick and is said to have produced a fair grade of agricultural lime. It is described as a "ferruginous limestone, compact, of a dark gray on fresh fracture, and somewhat brecciated" (2, p. 111). It has been recognized along the same stream below Zelienople. In the vicinity of Butler and along Coal Run southeast of Butler it is 3 to 4 feet

thick. It is present also in the northeast corner of Clearfield Township where it is markedly argillaceous in character.

Upper Freeport limestone. Next to the Vanport the Upper Freeport is the most important limestone in Butler County. It is, however, so decidedly inferior in comparison with the Vanport that it has never received much attention. No one would consider opening a quarry in this ledge if the Vanport could be obtained near by and no large quarries have been developed in it in Butler County. However, in the southern part of the county where the Vanport is almost everywhere concealed from view by overlying strata, the Upper Freeport was many years ago quarried and burned for agricultural lime on a small scale in a number of places. It averages about 3 feet in thickness and in most places contains appreciable amounts of iron and earthy matter.

The Upper Freeport is present in Adams Township where it was once quarried and burned but yielded poor lime because of its highly ferruginous character. Along Lardins Branch of Bull Creek in Clinton Township, about one mile above the Allegheny County line it is composed of two layers, each 2 feet thick separated by a 4-foot bed of sandy and argillaceous shale. "The upper one is quite compact and breaks with a clean, sharp fracture, while the lower one is very ferruginous and almost an iron ore" (2, p. 83). In various other places in Clinton Township it has been recognized. It is generally 2 to 3 feet thick.

In the vicinity of Monroe, Buffalo Township, it is 3½ to 5 feet thick. It is described as "very hard and compact and has a yellowish-brown color on its weathered surface." (2, p. 90). Near the mouth of Thorn Creek and also along the same stream in the eastern part of Penn Township the Upper Freeport is developed. It is about 3 feet thick, ferruginous and brecciated. It was once quarried and burned for lime about a mile above the mouth of Glade Creek where it is 3 feet thick. The lime was of poor grade. At Evansburg, it is 4 feet thick. In the vicinity of Harmony and along Breakneck Creek in Jackson Township the Upper Freeport is 2 feet thick and was at one time quarried for agricultural lime.

Along Little Connoquenessing Creek in the southwest corner of Connoquenessing Township it is 3 to 4 feet thick and was once quarried and burned. "It is very compact, of a light dove color on fresh fracture but contains much iron in the shape of nodules imbedded in it, which, not weathering away as rapidly as the limestone, give a very rough appearance. The lime from it is of a reddish white cast, and requires careful burning to get it to slack well" (2, p. 125).

In the vicinity of Butler the Upper Freeport is in places a solid ledge of limestone 3 feet thick and elsewhere a series of thin limestone beds through a band of shales and fire clay 10 to 12 feet thick. It was once burned for lime along Coal Run about 2½ miles southeast of Butler. It made poor lime because of its ferruginous and earthy constituents.

The Upper Freeport limestone is exposed in several places near Portersville where it is 2 to 3 feet thick. It outcrops at several points near Sunbury where it is 2½ to 3 feet thick and is associated with some nodular iron ore. It has been burned to a small extent but the resulting lime is of poor grade.

North of Middletown in Concord Township it is 2 to 4 feet thick. It appears in places in the highlands of Parker and Washington townships.

LIMESTONES OF THE CONEMAUGH GROUP

The *Brush Creek, Pine Creek,* and *Ames* limestones of the Conemaugh group have been recognized in Butler County but have little, if any, value. The *Brush Creek* limestone receives its name from its occurrence along Brush Creek, Cranberry Township, where it is a dark sandy limestone from 1 to 1½ feet in thickness.

The *Ames,* formerly called the Crinoidal limestone because of the abundance of crinoid fragments, is present near the tops of some of the highest knobs in the southern part of the county. It has been recognized in several places in the southern part of Adams Township where it has its typical characteristics wherever known in western Pennsylvania. It is greenish-black in color, well filled with fragments of crinoid stems and so impure as to be practically valueless. It was at one time quarried on a small scale and burned at a point between the headwaters of Glade and Breakneck creeks. It has been noted in Middlesex Township where it is 1½ feet thick, in a high knob south of Thorn Creek in Penn Township and in some high points above the headwaters of Little Bull Creek in Buffalo Township.

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CAMBRIA COUNTY

The limestones of Cambria County occur at different horizons in the Carboniferous formations. With the exception of the Loyalhanna, which strictly scarcely deserves the name of a limestone on account of its high siliceous content, the county does not contain any limestones of real economic significance. When it was the common custom for farmers to quarry small quantities of stone from hillside outcrops and burn lime for their own agricultural use and occasionally to supply their neighbor's needs in addition, these limestones were worked on a small scale in many localities but in recent years this practice has changed and very little use is now being made of any of these minor limestone beds.

The Loyalhanna furnishes excellent material for paving blocks, railroad ballast, and concrete aggregate so that it is valuable wherever it outcrops in the vicinity of favorable shipping points.

Prior to 1877 one of the argillaceous limestones near Johnstown was quarried and used in the manufacture of a natural cement but this operation has long since been discontinued. The stone used is unsuited for Portland cement because of its high content of magnesium and iron.

Generalized section

	Feet
Pennsylvanian System	
Monongahela group	
Pittsburgh coal	
Conemaugh group	960
Wilmore sandstone	
Summerhill sandstone	
Morgantown ("Ebensburg") sandstone	
Ames limestone	
Harlem (?) coal	
Pittsburgh red beds	
Saltsburg sandstone	
Bakerstown coal	
Buffalo sandstone	
Gallitzin coal	
Mahoning sandstone	
Allegheny group	290
Upper Freeport coal	
Upper Freeport limestone	
Bolivar clay	
Butler sandstone	
Lower Freeport coal	
Lower Freeport limestone	
Upper Kittanning coal	
Johnstown limestone (cement bed)	
Middle Kittanning coal	
Lower Kittanning coal and clay	
Kittanning sandstone	
Clarion coal	
Brookville coal	
Pottsville series	250
Homewood sandstone	
Mercer coal	
Mercer shale	
Connoquenessing sandstone	
Mississippian System	
Mauch Chunk series	200
Loyalhanna (Siliceous) limestone group	
Pocono series	1100
Burgoon sandstone	
Patton shale	
Catskill group	400

LOYALHANNA LIMESTONE

The *Loyalhanna limestone* is exposed in two places in the county, one in the valley of the Conemaugh and the other along the Little Conemaugh, both associated with structural uplifts. It appears in Conemaugh River in Westmoreland County a short distance west of the Cambria County line, rises above the river in the gorge, which is largely included within Cambria County, outcropping on both sides of the stream valley, and descends again to the river level about 2½ miles farther up the stream. The second outcrop is along the Little Conemaugh extending from Mineral Point up stream about 1½ miles

to a point near the mouth of South Fork. The Laurel Ridge anticline is responsible for its development in the Conemaugh River gorge and the Ebensburg anticline for its exposure along the Little Conemaugh.

The Loyalhanna limestone consists of layers in which silica predominates, alternating with those in which calcareous material is in excess. It is not a true limestone but rather a sandy limestone or calcareous sandstone. The calcareous part weathers more rapidly and leaves the siliceous layers in relief. This unequal weathering in conjunction with the crossbedded character of the rock gives it a highly distinctive appearance.

The Loyalhanna in these localities is about 45 feet thick. It is quarried and split into paving blocks and crushed for concrete and railroad ballast. It is well adapted for use in paving and as a ballast because the calcareous portion of the rock on solution and recrystallization tends to bind the fragments solidly together and yet leaves sufficient space between them to allow the free circulation of water.

LIMESTONES OF THE ALLEGHENY GROUP

Johnstown limestone. About Johnstown the Upper Kittanning coal is underlain by a limestone that has been used for the manufacture of natural cement. Because of its use in the manufacture of cement, this bed was long designated "Johnstown cement bed". It has also been called the "Ferriferous limestone" because of its high iron content and also because it at one time was regarded as the equivalent of the Vanport limestone which had been given the same name on account of the layer of iron ore that commonly overlies it.

This limestone is best developed along Stony Creek and may be seen to advantage in the cuts on the Baltimore & Ohio Railroad north of King station. Here it is 6 feet thick and is separated from the coal by 8 to 12 inches of shale. Along the spur track leading from the north end of the tunnel it is also conspicuous but slightly thinner. "The bed is nearly 8½ feet thick near Conemaugh station and nearly 5 feet thick in the section along the Pennsylvania Railroad to the west near Johnstown station. To the east on Little Conemaugh River it is exposed just at the northwest apex of the first big meander. It must be thick in all the intermediate territory. Its outcrop along Stony Creek near the Rolling Mill mine of the Cambria Steel Company is also conspicuous. Northwest of Johnstown near the old Cambria furnace and at the east base of Laurel Hill it outcrops and shows just above the waters of Laurel Run. Here it is a bluish limestone with some streaks of calcite. It is present but not very thick near South Fork, and is also reported near Scalp Level." (Johnstown Folio, pp. 5 and 14.)

At Johnstown A. J. Hawes, at one time, made a natural cement from this limestone. The plant was known as Hawes "Cement Works". The limestone used was described as "hard and brittle, showing small crystals of iron pyrites. It contains considerable clay; color, bluish gray." It emitted a strong argillaceous odor when breathed upon. An analysis by McCreath (3, p. 295) is as follows: $CaCO_3$ 34.301, $MgCO_3$ 21.650, $FeCO_3$ 8.700, Al_2O_3 3.300, FeS_2 1.268, P .049, Insoluble residue 27.873.

A partial analysis of the Johnstown limestone at the old Cambria furnace, northwest of Johnstown and near the base of Laurel Hill,

where it was much purer and bluish in color with occasional streaks of calcite as determined by T. T. Morrell (2, p. 154) is as follows: $CaCO_3$ 86.93, Al_2O_3 .62, Fe 1.46, SiO_2 3.56, other substances not determined.

Near the big bend of Black Lick Creek in Barr Township the Johnstown limestone, about 5 feet thick, occurs in two layers separated by 1 foot of fire-clay shale. On account of its high content of iron carbonate, it was called a low grade iron ore. Two analyses of samples made by McCreath (Report HH, p. 160) are as follows: $CaCO_3$ 34.580, $MgCO_3$ 12.008, $FeCO_3$ 29.414, Fe 14.200, Al_2O_3 2.412, S .285, P .084, Insoluble residue 21.305.

A later analysis published by U. S. Geological Survey[6], is as follows:

Analysis of cement rock, Mineral Point

SiO_2	4.97
Al_2O_3	2.57
Fe_2O_3	.56
MnO	.48
CaO	48.36±
MgO	1.21±
SO_3	.13
Na_2O	.08
K_2O	.53
H_2O at 100°C.	.09
Ignition loss	41.17

Sample collected by Lawrence Martin, near Mineral Point. Analyzed at Structural-materials laboratory, U. S. Geological Survey, St. Louis. A. J. Phillips, analyst.

The analyses and descriptions given indicate clearly that in this section the Johnstown limestone has little value. It could not have made a high quality natural cement and certainly not a uniform product, and at best natural cement at present is scarcely used because of the superiority of Portland cement. For agricultural lime it is fairly satisfactory, but with the virtual disappearance of the small lime plants it has almost completely passed out of use. No recent quarrying of this bed is known to the writer.

Lower Freeport limestone. "The Lower Freeport limestone member occurs either directly below or within a foot of the base of the Lower Freeport coal, the separating beds as a rule being black shale. It varies from 1½ to near 4 feet in thickness, and the best exposures seen occur along Stony Creek and the Baltimore & Ohio Railroad between Moxhom and the mine of the Valley Coal and Stone Company. The limestone has never been used in any way." (8, p. 14.)

This limestone appears to be sparingly developed near Gallitzin where it is said to be about 10 feet thick and is decidely impure.

Upper Freeport limestone. "The Upper Freeport limestone member appears near South Fork and Ehrenfeld. A short distance east of Ehrenfeld station it is exposed in some excavations along the main line of the Pennsylvania Railroad, where it ranges from 1½ to 3 feet in thickness. It is a gray limestone, and at Ehrenfeld it is very irregularly bedded. It lies a short distance below the Upper Freeport coal, from which it is separated by about 2 feet of clay containing limestone nodules in its lower half. So far as known, this particular limestone has never been used in this section." (8, p. 14.)

On Bens Creek about 2½ feet of limestone has been reported. It is probably the Upper Freeport. Another limestone, higher in the section, is 7 feet thick.

LIMESTONES OF THE CONEMAUGH GROUP

Here and there throughout the county thin beds of limestone have been encountered within the Conemaugh group. According to report they have at different times furnished some stone for agricultural use but they are certainly of little value. With the exception of the Ames, which is one of the most distinctive Carboniferous limestones of western Pennsylvania, these limestones are difficult of correlation with similar limestones in adjoining regions. The following brief descriptions give an idea of the general characteristics of the limestones. Undoubtedly there are many other similar occurrences within the county.

"About 2 miles east of Ashville (9, p. 12) a limestone bed supposed to be 130 feet above the Freeport coal has been opened to a thickness of 6 feet. The stone is hard, compact and appears to be of good quality. An entire thickness of 15 feet is reported, but the report is probably exaggerated. A short distance west of Chest Creek at Eckenrode Mill a gray flint-like limestone was once opened. About a mile northwest of Winterset a bed of hard gray limestone has in the past been burned for lime."

"A somewhat typical section of a limestone in the Conemaugh formation, exposed on the Pennsylvania Railroad about a mile northwest of Loretto Road station is as follows:

Section in railroad cut near Loretto Road

	Ft.	in.
Coal		3
Sandstone, calcareous		9
Limestone, brownish, earthy		7
Shale, sandy with layers of calcareous sandstone	1	8
Limestone, earthy	1	8
Shale		4
Limestone, drab	1	6
Shale, soft, gray	1	2
Limestone, earthy	2	

In addition to the outcropping limestones a number are known only from records of borings."

The *Ames limestone* from 4 to 6 inches thick has been identified about three-fourths mile north of Bradley Junction and about 1¼ miles southwest of Eckenrode Mill.

The limestones of the Conemaugh formation are of no importance in the region about Johnstown. A limestone, considered to be the Ames, appears in a railroad cut near the old dam site on South Fork. It is about 1 foot thick.

"Thin bands of yellow limestone occur between the Ebensburg (Morgantown) sandstones. These limestones may be seen in the cuts between Portage and the mouth of Laurel Run. They also crop out in the ravines along North Branch of the Little Conemaugh. In but

few places do they reach a thickness of 5 feet or over. They might be utilized in a limited degree for lime to make fertilizer, in case they were found cropping out in a favorable situation for quarrying. It is not likely, however, that they will ever be developed to any great extent." (7, p. 9.)

Just east of the railroad station at Wilmore, a limestone 8 feet in thickness has been reported but it is probably very impure.

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CAMERON COUNTY

Fragments of limestone resembling the Vanport are reported (1, pp. 51-52) to have been found on Sterling Run in Cameron County. With this exception, no limestones are known to occur in the county, although the horizons at which the Vanport and other limestones occur in other regions are present. It is possible that some are present although it is doubtful whether any limestone of economic importance is developed within the county.

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CARBON COUNTY

The limestones of Carbon County are of little importance. Both the Helderberg and Onondaga limestones cross the county in narrow bands in the valleys of Aquashicola and Lizard creeks. Almost everywhere, however, they fail to show because of the cover of glacial debris and hillside talus of Oriskany sandstone. Both were once quarried on the south slope of Stony Ridge just to the north of the west part of Palmerton. In the tunnels driven into Stony Ridge to obtain the metallic paint ore so long mined only in the general vicinity of Little Gap, Palmerton and westward from Bowmanstown and from exposures along the Lehigh River, the following section has been compiled by the geologists of the Second Geological Survey (2, p. 129, 3, pp. 1374-1376).

Generalized section in south part of Carbon County

	Feet
Marcellus group, dark friable shales	?
Onondaga group	
Argillaceous limestone, commonly called "hydraulic cement rock"	1 to 50
Clay	1/2
Metallic paint ore, fossiliferous blue carbonate of iron limestone	0-2 2/3
Clay	4-10
Oriskany group.	
Coarse, massive reddish-gray quartz conglomerate, nearly destitute of fossils	200
Cherty calcareous sandstone containing casts of fossils	10
Shales, containing some cherty layers together with a few thin beds of sandstone	60
Concealed	20
Shales with thin layers of reddish sandstone	50
Helderberg group.	
Greenish shales and calcareous sandstone (Decker's Ferry)	30
Limestone, blackish, slaty fracture, filled with streaks of calcite (Bossardville)	40
Shales, buff, gray and greenish, calcareous, variegated with red near the base	225
Clinton group.	

Within recent years it seems that no use has been made of the limestones of Carbon County. The quarry in the Helderberg on the slope of Stony Ridge at Palmerton was worked for lime. It is described by H. M. Chance (2, p. 358) as follows:

"Another portion of the formation (Helderberg) is seen at the quarry N. E. from Hazardville. It here yields a very fair lime, but the workable bed is quite thin. Twenty feet of limestone are exposed in the quarry overlaid and underlaid by slaty limestone and lime shale. It is much lighter in color than at the quarries opened at the Delaware gap, and is also softer, yielding much more readily to erosion. Its lower layers are hydraulic.

"It has been found in several water wells near the pike, at Millport.

"Its lower beds as seen along the L. and S. R. R. consist of

Fossiliferous lime shale of a purplish color, which may belong to the water-lime group	3′
Shaly limestone with nodular chert	4′
Sandy lime shale containing some beds of workable limestone	52′
Total	59′

"Over this mass occurs a series of lime shale and limestone beds classed as Lower Helderberg lime shale, which graduate upward into the Oriskany shales; but as the exposures are very poor, I have been unable to determine any line of demarkation between these two shale groups. The section stands:

Oriskany shales, measured	14′
Oriskany and Lower Helderberg shales, unexposed	170′
Lower Helderberg limestone, measured	69′

The so-called "hydraulic cement rock," which was once quarried according to a map by Chance (2), less than a quarter of a mile to the north of the Helderberg quarry, was used for the manufacture of natural cement. Hill (3, p. 1389) describes it as follows: The argillaceous limestone of the Onondaga "is a cement bed, and is found at every point where the paint bed has been observed. It is a very hard, fine-grained, hydraulic limestone. It thickens and thins; at some places being but one foot thick, while in others it reaches a thickness of 50 feet.

"This cement was worked for a great many years, and it is said that all the masonry of the Lehigh canal was laid with it. The way it has stood is certainly a recommendation of its quality. The fact, however, that none of it is mined at the present day, although the opportunity for cheap mining and transportation is of the best, would seem to indicate its inability to compete with the cements of the present market.

"This cement is probably the representative of the Upper Helderberg or Corniferous limestone."

Chance (2, p. 355) gives a slightly different description of the same exposure, as follows:

"At the Lehigh, this formation almost altogether loses its character as a chert-bearing limestone.

"It is here composed of 20 feet of hydraulic cement lime, overlaid by 5 feet of cherty lime.

"The cement has for many years been worked at a quarry near the paint tunnel at Hazardville.

"It is said to produce a superior quality of cement. All the masonry of the Lehigh and Susquehanna canal was laid with it, and the way it has worn certainly does not condemn it. It is burnt and ground by Mr. Prince of the Lehigh Metallic Paint Company, but at present (1875) very little is quarried.

"The 5 feet of overlying cherty limestone is precisely like that seen to the N. E. at the Delaware River and in New Jersey.

"The formation as a whole is soft, and presents but few natural exposures."

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CENTRE COUNTY

Centre County is one of the most important limestone producing counties of the State. It has achieved this rank not because of the great area of outcropping limestones, although few counties have an equal limestone surface, but because of the development of one of the best, if not the best, grades of limestone within the State. The so-called Bellefonte ledge has long supplied those limestone users who demand the best grade of stone obtainable. In addition to these high grade limestones the county contains almost unlimited quantities of limestones of poorer quality but suitable for a variety of purposes.

The following geological section of Centre County has been prepared by the members of the Department of Geology at Pennsylvania State College.

*Geological section of Centre County**

	Feet
Pennsylvanian System	
Coal Measures	
Pottsville series, conglomerate and sandstone	
Mississippian System	
Mauch Chunk series. Green and yellow shale and sandstone	20
Pocono series. Gray, brown, green and red sandstone and conglomerate	1025
Devonian System	
Catskill group. Red, chocolate, and green shale and sandstone ..	1200-1600
Chemung group. Gray, purple, brown, and drab shale and sandstone with thin beds of conglomerate	2883
Portage group	
Brallier shale. Black, brown, and drab shales and fine-grained sandstones	1658
Harrell shale. Fissile, very thin-bedded carbonaceous, black and drab shale	300
Hamilton group. Brown, black and purple shale with impure limestone near the top.	610
Marcellus group. Brown, and black shale.	100
Oriskany group	200
Ridgely sandstone	
Shriver chert and limestone	
Helderberg group. Keyser and New Scotland limestones	150
Silurian System	
Cayugan series. Mackenzie (base) limestone, Wills Creek shale (?) and Tonoloway limestone (top)	698
Clinton group. Brown and green soft shales and limestone	890+
Tuscarora group. White, gray, and purple sandstones and quartzites	495
Silurian or Ordovician System	
Juniata group. Red shales and sandstones	490-700
Oswego group	838
Ordovician System	
Reedsville series. (Hudson River, Martinsburg), Black, brown and drab, slaty shales and sandstones	825
Trenton group. Highly fossiliferous thin-bedded limestone and black to brown shale	791

*This section has been arranged to follow the official section of the Pennsylvania Geological Survey although the author prefers the U. S. Geological Survey section which does not include the Canadian System.

Black River group. This group includes the Rodman (upper) and Lowville (base) limestones, which are usually pure, blue to gray rocks. The Lowville contains the important quarry rock.	182
Canadian System	
Chazy series (Carlim at base). Bluish limestone	260
Beekmantown series	
Bellefonte group. Dolomite with a thin bed of red sandstone	1911
Axemann group. Pure fossiliferous limestone with dolomitic limestone, oolitic limestone and reddish conglomerate	480
Nittany group. Coarse, light to dark dolomite with much chert in lower portions	1206
Stonehenge group. Limestone, "edgewise" conglomerate, limestone conglomerate, and calcareous shales	633
Mines group. Cherty dolomite and siliceous oolite	150
Gatesburg group. Interbedded dolomite and sandstone	800
Cambrian System	
Warrior group. Limestone, oolitic limestone, and beds of shale	688

In the table above it will be noted that limestones occur at several different horizons and aggregate in all several thousand feet in thickness. For our purpose it seems advisable to discuss them under the divisions of Cambro-Ordovician, Helderberg (including Tonoloway), other Silurian and Devonian, and Carboniferous limestones.

CAMBRO-ORDOVOCIAN LIMESTONES

The structure of all the Cambro-Ordovician limestone valleys of the central part of the State is very much the same. After the deposition of these and overlying strata that outcrop in Bald Eagle Ridge and in the Allegheny Mountains the whole region was thrown into great longitudinal folds, approximately parallel, with a northeast-southwest trend. Erosion then became active and after many thousands of years the ridges were obliterated and a broad low-lying plain resulted, in which there was little or no difference in elevation based on the character of the rocks.

A second uplift again started erosion, and the wearing away of the least resistant rocks, the limestones, soon formed the valleys. It so happens that these limestones are the oldest rocks of the region and thus constituted the cores of the old ridges, or anticlinal folds. Above the centers of these limestone valleys, where, consequently, the greatest amount of material has been removed, it is estimated that a restoration of these old folds would give us mountains over 20,000 feet in height, possibly as much as 25,000 to 30,000 feet. It is improbable that such mountains ever did exist as the uplift was a slow process, and erosion was wearing down the elevated portions simultaneously, yet mountains of very considerable height must have existed at the close of the folding.

By this major structure that is everywhere prominent, the youngest limestones are found at the edges of the valleys where they dip beneath the shales and sandstones that constitute the ridges. In general the strata dip steeply on the northwest sides of the valleys and more gently on the southeast sides, which seems to indicate that the compressive movement proceeded from the southeast toward the northwest.

In addition to the major structures, there are occasional subordinate

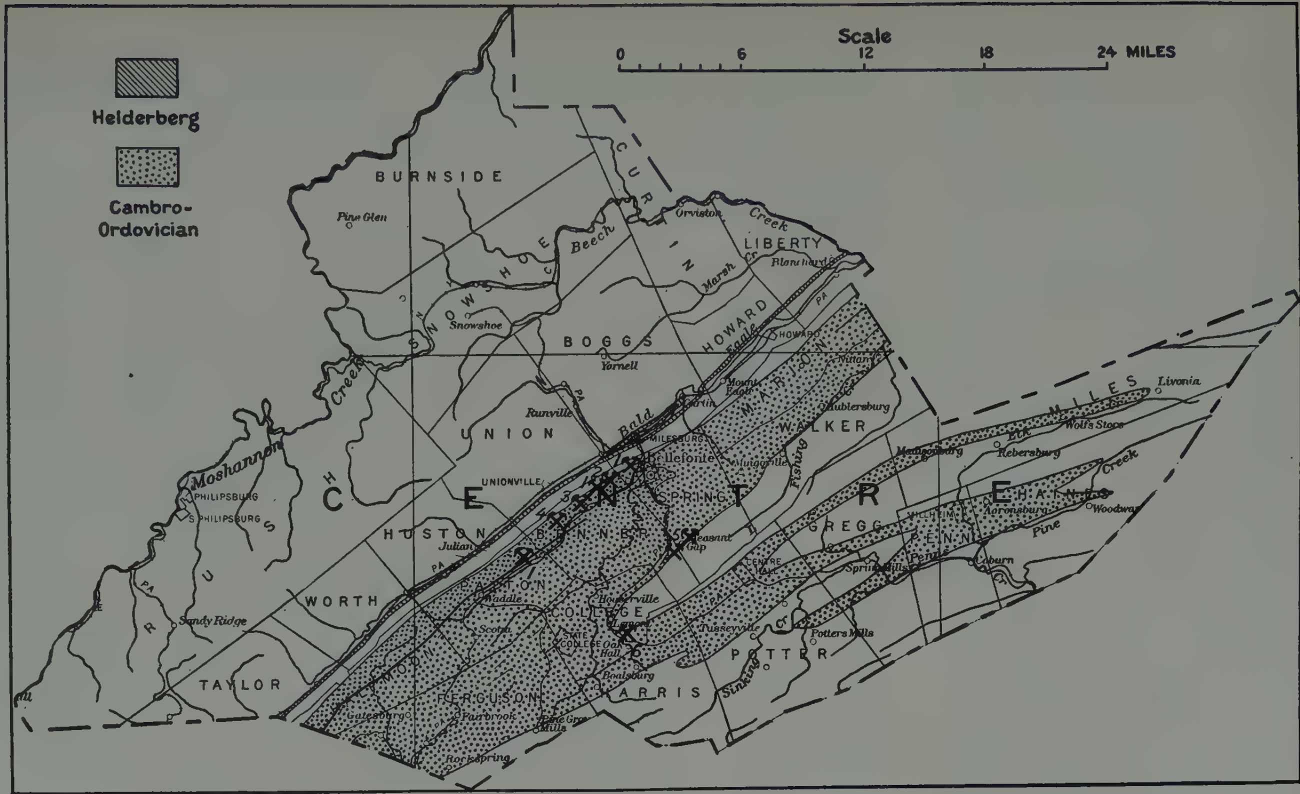

Fig. 7. Limestone areas in Centre County.

1. American Lime and Stone Co.
2. Chemical Lime Co.
3. Centre County Lime Co.
4. M. J. Miller
5. White Rock Quarries
6. Oak Hall Lime and Stone Co.

crumples or folds that are roughly parallel to the main folds. Also the strata have been broken in places and one side offset with reference to the other. Offsets or faults of this kind have been observed in several places. In one place near Bellefonte the displacement as observed at the surface is about a quarter of a mile.

Nittany Valley, with maximum width of about 9 miles, is the most important of these anticlinal valleys. Brush Valley and Penns Valley, produced by minor folds, are off-shoots of this main valley. Nippenose Valley, the larger portion of which is within Lycoming County, although separated from Nittany Valley by high land underlain by sandstone, is in line with it and constitutes a part of the same fold. The intervening area was not uplifted quite as high so was not worn down in the great erosion period sufficiently to uncover the limestones. Sugar Valley, which likewise is detached from Nittany Valley, has been produced by the erosion of limestone elevated by a small distinct fold.

As indicated in the table of formations, Centre County contains a great variety of limestones. They are adapted to almost all the uses to which limestones have been put. Scores of quarries have been opened throughout the county to provide building material, mainly for foundations, walls, etc., for stone to be burned for agricultural lime, for road metal and concrete, and for flux. As in other parts of the State local burning of lime has almost ceased and the small kilns are in ruins.

During the period when the numerous limonite iron ore mines were in active operation limestones were quarried extensively in the vicinity of the furnaces for flux. These quarries were abandoned when the iron industry died and the only ones that have continued to furnish flux are those that have low-silica stone and are favored with good shipping facilities.

The increased demand for crushed stone for road metal and concrete has resulted in the opening of many quarries, but in most cases only to supply local needs. Nearly all the limestones of the county will meet the specifications of the State Highway Department.

In recent years the manufacture of high grade lime in the county has developed rapidly. This has been possible because of the existence of a band of limestone within the Lowville member of the Black River group that is in many respects the best limestone within the State. Although it has been recognized in adjoining counties, it presents its best phase in the vicinity of Bellefonte, where it also seems to be thickest. It averages nearly 98 per cent $CaCO_3$, almost 1 per cent $MgCO_3$, the balance is SiO_2, Al_2O_3 and Fe_2O_3. At Bellefonte, the best stone is 77 feet thick, but it thins in both directions and in some places throughout the valley no stone of this character has been found at this horizon.

The Bellefonte ledge so far overshadows in importance all the other limestones of Centre County that it alone receives much attention. The principal operations are in the vicinity of Bellefonte, yet the ledge apparently has been traced to the southwest into Blair and Huntingdon counties and elsewhere in Nittany Valley, as well as in the other limestone valleys of the county. It is probably not continuous but is decidedly lenticular in character. In many places it could not be worked

economically at the present time because of the thick clay overburden and deep solution pockets filled with clay or sand. Also satisfactory transportation facilities are lacking in many places and it would be expensive to provide them. Structural difficulties such as displacements by faulting and complex folding are obstacles that might seriously interfere with operations in some localities. Nevertheless there are probably additional desirable sites where quarrying may be carried on when market conditions seem to warrant any expansion of the present industry.

The best stone is mainly utilized by the chemical industries demanding practically pure raw limestone or lime. Underlying this band is limestone of good quality, but slightly higher in silica than is satisfactory for fluxing stone and crushed stone. These two varieties of stone have been worked in the same quarry, thus supplying a wide market. The overlying strata are largely dark-colored shaly limestones but are not of much value.

The Bellefonte ledge consists of a gray to dove-colored, compact, fine-grained limestone that breaks with a conchoidal or glassy fracture. It contains many specks or larger pieces of crystalline calcite that, breaking along cleavage planes, glisten on a broken surface. The stone is soft and easily crushed. The beds are generally massive. The underlying beds of second grade stone are harder and light to dark blue in color.

The Bellefonte ledge is similar in composition throughout the entire district where it has been worked, but varies considerably in dip and in thickness. On the north side of Nittany Valley, close to Bellefonte, the dips are steep, ranging from 45° to 90° NW. On the south side of the valley the dips are much more gentle, apparently ranging from 20° to 30°SE. The thickness is variable, with the maximum about 80 feet and the minimum where worked about 35 feet. In Blair and Huntingdon counties, it is less and may be less in some places in Centre County. In a few places the band thins locally by what appears to be a downward bulge of the overlying black limestones. These thinner portions may represent contemporaneous erosion of the high-lime beds before the deposition of the overlying shaly limestones or they may have resulted from slight faults. Slickensided surfaces indicating displacements have been observed by the writer in a number of places. Most of the faults are small, but one of considerable displacement was observed in the quarry of the Chemical Lime Co. and one that has thrown the outcrop of the ledge about one-fourth mile to the south lies east of Bellefonte.

In the mine of the American Lime and Stone Co., water channels, more or less filled with surficial sand and detrital clay, have been found in a few places. These water courses are more or less tubular in character and continue rather persistently down the dip in a single stratum of the stone. When encountered in drifting, a considerable amount of clay, sand and water have entered the working. Some of these tubes are 2 to 3 feet in diameter, large enough to permit a person to crawl in them for long distances. In one of the quarries, a small cave was observed, but in general solution cavities are not numerous.

All of the operations in the region were started as open cut quarries, but as they were continued downward, the overburden of useless rock

increased until open cut quarrying became dangerous and expensive. The American Lime and Stone Co. began underground mining about 1920 by sinking an inclined shaft in the footwall of the band of good stone and working the stone by the shrinkage stope method. In 1929, the company was obtaining all of its high grade stone from the mine. Although the cost of mining is somewhat greater than shallow open cut quarrying, the stone is so much cleaner that it is profitable where the product is high grade and the strata as regular as they are in the Bellefonte region. One or more of the other companies of the district will eventually resort to mining. By mining, certain other portions of the Bellefonte ledge can be worked where at present quarries have not been opened due to the thick overburden of residual clay.

There are four active companies quarrying and mining the Bellefonte ledge in Centre County. These are the American Lime and Stone Co. (affiliated with the Warner Co.), the Chemical Lime Co.,

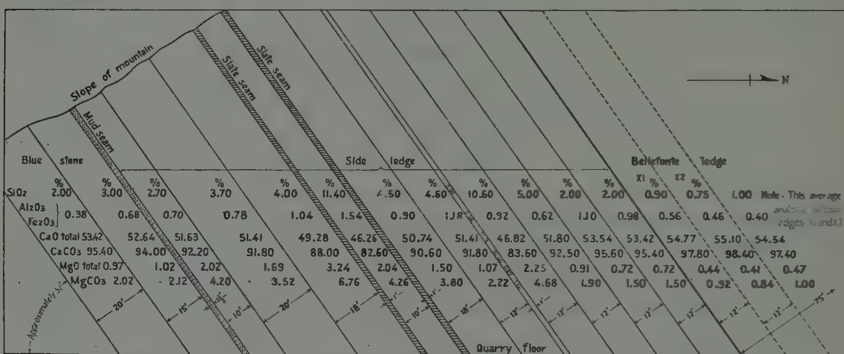

Fig. 8. Diagram of ledges in Warner Company quarry No. 3, Bellefonte

and Martin J. Miller, all operating on the north side of Nittany Valley from Bellefonte westward about 5 miles and the Whiterock Quarries operating on the opposite side of the valley on both sides of Pleasant Gap village.

The American Lime and Stone Co. has one of the best equipped limestone plants in the State. The company has 12 quarries and one mine and owns additional undeveloped property. Their reported annual capacity is given as 95,000 tons of quick lime, 50,000 tons of hydrated lime, 100,000 tons of ground and pulverized limestone, and 200,000 tons of crushed limestone. They have 18 shaft kilns and 2 rotary kilns for burning lime.

The table that follows shows the chemical composition of the limestone being mined. This will serve to illustrate the high grade, character, and uniformity of the Bellefonte ledge for the district. It perhaps averages somewhat better than that in some of the open cut quarries but in general these analyses are typical of the ledge of good stone.

*Analysis of cross section of mine of American Lime and Stone Co.**

Sample No.	Distance from hanging wall	SiO_2*	$Al_2O_3+Fe_2O_3$	CaO	MgO	$CaCO_3$	$MgCO_3$
	feet						
1	0	1.20	0.50	54.40	0.57	97.14	1.20
2	1.3	1.05	0.50	54.50	0.57	97.32	1.20
3	2.6	1.70	0.60	54.20	0.48	96.79	1.00
4	3.9	1.00	0.30	55.20	0.14	98.57	0.30
5	5.2	0.70	0.22	54.90	0.58	98.04	1.21
6	6.5	0.80	0.32	54.50	0.57	97.32	1.20
7	7.8	0.80	0.30	54.70	0.57	97.68	1.20
8	9.1	0.64	0.64	54.40	0.72	97.14	1.51
9	10.4	0.60	0.44	55.00	0.55	98.21	1.14
10	11.7	1.00	0.40	54.50	0.65	97.32	1.36
11	13	0.60	0.30	55.00	0.43	98.21	0.90
12	14.3	0.40	0.28	55.00	0.57	98.21	1.20
13	15.6	0.80	0.40	55.20	0.14	98.57	0.30
14	16.9	0.35	0.30	55.40	0.19	98.93	0.40
15	18.2	0.35	0.24	55.00	0.57	98.21	1.20
16	19.5	0.60	0.30	54.88	0.54	98.00	1.13
17	20.8	0.50	0.28	54.50	0.86	97.32	1.80
18	22.1	0.56	0.44	54.60	0.69	97.50	1.45
19	23.4	0.60	0.40	54.50	0.81	97.32	1.70
20	24.7	0.80	0.40	55.00	0.31	98.21	0.65
21	26	0.80	0.30	55.30	0.14	98.75	0.30
22	27.3	0.62	0.30	55.20	0.29	98.57	0.60
23	28.6	0.80	0.40	54.50	0.72	97.32	1.50
24	29.9	0.70	0.50	55.00	0.29	98.21	0.60
25	31.2	0.55	0.36	54.90	0.48	98.04	1.00
26	32.5	1.00	0.60	54.50	0.50	97.32	1.05
27	33.8	0.50	0.50	55.30	0.14	98.75	0.30
28	35.1	0.50	0.50	55.00	0.38	98.21	0.80
29	36.4	0.30	0.32	55.00	0.57	98.21	1.20
30	37.7	0.30	0.50	55.50	----------	99.11	Trace
31	39	0.70	0.30	55.50	----------	99.11	Trace
32	40.3	0.50	0.35	55.00	0.48	98.21	1.00
33	41.6	0.70	0.20	55.00	0.38	98.21	0.80
34	42.9	0.35	0.40	55.30	0.24	98.75	0.50
35	44.2	0.30	0.38	55.30	0.24	98.75	0.50
36	45.5	0.80	0.80	54.70	0.38	97.68	0.80
37	46.8	0.80	0.80	54.60	0.38	97.50	0.80
38	48.1	0.90	0.88	54.70	0.29	97.68	0.60
39	49.4	0.60	0.60	54.50	0.72	97.32	1.50
40	50.7	0.75	0.55	54.20	0.91	96.79	1.90
41	52	0.75	0.60	54.70	0.48	97.68	1.00
42	53.3	0.40	0.40	55.20	0.33	98.57	0.70
43	54.6	0.30	0.30	54.70	0.86	97.68	1.80
44	55.9	0.30	0.30	55.00	0.53	98.21	1.10
45	57.2	0.30	0.35	55.00	0.53	98.21	1.10
46	58.5	0.60	0.40	55.00	0.36	98.21	0.75
47	59.8	0.40	0.40	55.20	0.33	98.57	0.70
48	61.1	0.50	0.32	55.00	0.48	98.21	1.00
49	62.4	0.50	0.50	54.70	0.65	97.68	1.36
50	63.7	0.50	0.50	54.50	0.81	97.32	1.70
51	65	1.20	0.30	54.40	0.67	97.14	1.40
52	66.3	1.20	0.70	54.40	0.48	97.14	1.00
53	68	0.50	0.40	55.00	0.43	98.21	0.90
54	69.3	1.00	0.20	54.70	0.57	97.68	1.20
55	70.6	0.55	0.20	54.70	0.76	97.68	1.60
56	71.9	1.20	0.80	54.20	0.62	96.79	1.30
57	73.2	0.55	0.90	54.20	0.86	96.78	1.80
58	74.5	1.05	1.40	53.50	0.96	95.54	2.00

* Represent actual silica and not silica and insoluble matter.

The thicknesses of the individual beds given is not the true thickness inasmuch as the measurements were made along a horizontal line and the beds at that point dip probably 45° to 50°. The accompanying chart gives details of all ledges in the quarry and mine.

The Chemical Lime Co., with which the Centre County Lime Co. has recently merged, has several quarries in the same band as those of the American Lime and Stone Co. and interspersed with them. They produce both high grade and second grade stone. The annual

*Beginning at the hanging wall or north side of the third level in the mine, 58 samples were taken over a cross section of 75 feet and numbered from 1 to 58. The samples were taken as accurately as possible every 1.3 feet apart. Sampling extended over several days about June 29, 1925.

capacity of the combined plants is given as 53,000 tons of lump lime, 50,000 tons of hydrated lime, 250,000 tons of fluxing stone, 50,000 tons of agricultural ground limestone, 75,000 tons of glass house stone, 25,000 tons of pulverized stone for mine dusting, and 350,000 tons of crushed stone.

Martin J. Miller is working a quarry about one mile north of Hunter Park, the most westerly active operation of the Bellefonte ledge in Centre County. The strata are practically vertical. The opening is about 200 feet long and 70 feet wide. The Trenton limestones not forming a secure north wall, 10 to 12 feet of the good limestone has been left in the quarry. The opening is on the side of a rather steep hill and a tunnel has been run on the level of the quarry floor through the lower beds to strike the Bellefonte ledge and thus avoid hoisting the stone. Open-hearth fluxing stone has been the chief production but some is burned for lime and a few years ago some stone beneath the high grade stone was quarried for blast furnace use.

The Whiterock Quarries Co. has several quarries at Pleasant Gap village. The plant is located west of the village where the first quarries were opened, but more recently a large quarry has been opened east of the highway and village. The strata dip about 18° to 30° toward Nittany Mountain. The Bellefonte ledge as worked is about 40 feet thick, but in addition some of the massive blue stone of second grade quality is also worked. The annual plant capacity is given as 60,000 tons of lime, 75,000 tons of pulverized limestone, and 400,000 tons of crushed stone.

Just north of Oak Hall, the Oak Hall Lime and Stone Co. has operated a quarry to secure blast-furnace fluxing stone, crushed stone, and some building stone. The Bellefonte ledge appears to be missing. The strata strike N67°E and dip 58°NW. On the north side of the quarry the beds appear to belong to the Rodman member of the Black River formation, and to the Carlim on the south side. In 1929 the principal production was crushed stone, but some building stone was also being quarried. The building stone was of two kinds, one a dark blue stone with a rather rough surface and the other a light gray stone with a smooth fracture surface. These beds are 3 to 5 inches thick. The quarry has not been operated on a large scale.

On the slope of Nittany Mountain northeast of Lemont considerable drilling was done a few years ago to determine the availability of the stone there for the manufacture of Portland cement. The results were favorable but the cement plant was not built. The Trenton limestone in places seemed to have almost the composition needed for Portland cement, but in addition the high lime underlying strata could be used to supply any deficiency in the $CaCO_3$ and the overlying Reedsville shales to bring down any excessive lime composition. The $MgCO_3$ is sufficiently low. Whenever market conditions warrant the erection of a Portland cement plant in the region, there seems to be little doubt but that an abundance of satisfactory stone advantageously located can readily be found.

The property investigated has the following formations outcropping in successive bands on the flanks of Nittany Mountain: Bellefonte dolomite, Carlim and Black River limestones, Trenton limestone, and Reedsville shale. The following descriptions are taken from a report prepared for the prospective cement company.

"The Carlim and Black River limestones are described together because they consist of essentially the same kind of material, i. e., chiefly massive, dark gray, pure limestone, low in magnesia with some impure beds near the top and bottom which contain more silica and alumina."

"The Black River formation consists of two members, an impure argillaceous (clayey) limestone, (Rodman member), and very pure 'chemical lime' beds, (Lowville member). * * * Outcrop samples of this rock, collected on the property, showed the same character as at Pleasant Gap and Bellefonte."

"The Carlim and Black River formations are relatively free from flint and other concretionary nodules which are hard to grind. The combined thickness of these two formations is about 450 feet; their combined width of outcrop is 700 feet and their length on the property about 1½ miles."

"The Trenton formation is an impure argillaceous limestone with some thin, interbedded, calcareous shale beds. It is thin-bedded, dense, dark gray to black rock containing from 75 to 90 per cent $CaCO_3$, about 3 per cent $MgCO_3$, and from 7 to 22 per cent silica, alumina, and iron oxides. Its outcrop lies next to the Black River formation. This formation is the same as that quarried so extensively as a Portland cement rock in the Lehigh district. The physical appearance is slightly different due to the fact that it has not suffered metamorphism to the same extent as the Lehigh rock in which the bedding has been largely obliterated.

"Chemically it is quite similar to the Lehigh rock. In percentage of calcium carbonate the basal portion appears to be 5 to 10 per cent higher, 3 to 5 per cent lower in alumina and iron oxides and also a little higher in silica."

"A sample taken from twenty-five feet of rock exposed in a quarry about 300 feet above the base in the lower middle portion of the Trenton formation gave the following analysis: calcium carbonate 78 per cent, silica 14, alumina and iron oxides 4.14, magnesium carbonate 3.45. These analyses show that the Trenton is a natural cement rock requiring very little additional limestone or shale for Portland cement."

"The total thickness is about 800 feet, its width across the outcrop 1300 feet and its length 1½ miles on the property."

"Above the Trenton along the flanks of the mountain lie about 800 feet of dark gray, fissile shale known as the Reedsville formation." "Analyses of these cores showed an ideal composition for mixing with the Black River and Carlim limestones for the manufacture of Portland cement. The rock averages silica 57 per cent, alumina and iron oxides 30, magnesium carbonate 3, and calcium carbonate 2 per cent. Physically this shale is very fine grained and contains no large particles of chert or quartz pebbles but occasionally fine grained sandstone layers."

The Cambria Steel Co. made many examinations of the limestones of Centre County a few years ago in their endeavor to locate deposits of high-grade fluxing stone. They finally acquired a property a short distance south of Millheim where a quarry has been opened. Rock from two drill holes was analyzed for silica alone, as follows:

Silica in limestone near Millheim, Centre County

East of Elk Creek		West of Elk Creek	
Percent SiO_2	Thickness Feet	Percent SiO_2	Thickness Feet
8	50	8	75
3.24	25	3.65	20
0.77	80	1.95	90
3.4	30	5.83	25
7.0	20	2.6	50
2.7	50	7	?
7	?		

Sugar Valley was examined and near the western end some very low-silica limestone was found that might be worked with profit if a railroad entered the valley.

In the vicinity of Spring Mills, both east and west of the village, there is some fairly low-silica stone and also about 2 miles slightly north of east of Coburn.

In addition to the quarries described there are numerous other small openings throughout Nittany Valley, Brush Valley, and Georges Valley that in the past have been worked to supply small quantities of limestone for making agricultural lime and to a smaller extent for building purposes. Some of these have furnished crushed stone for highway construction in recent years. There is within the county an almost unlimited amount of limestone suitable for all uses for which crushed stone is employed and it is developed in all of the limestone valleys mentioned. This wide distribution makes it possible to build good roads it less expense than in some other parts of the State.

Mention should be made of the limestone caves that have formed in the thick deposits of limestone in Centre County. Several have been discovered and explored but most are of small size. The most noted and one of the largest and best known within the State is Penn's Cave located about 5 miles northeast of Centre Hall. Emerging from underground channels in these limestones are also some large and famous springs.

Another item of interest is the discovery of several thin beds of bentonite in the Ordovician limestones of Centre and adjoining counties by Professor C. A. Bonine. He reports 7 beds varying from 1 to 14 inches in thickness. Of these, 4 are in the base of the Trenton, one in the Lowville limestone, and two in the Carlim limestone.

Additional analyses of Cambro-Ordovician limestones of Centre County

	1	2	3	4a	4b	4c	4d
$CaCO_3$	97.890	98.322	97.532	98.03	98.05	98.00	93.45
$MgCO_3$	1.285	1.170	1.210	0.80	0.79	0.96	2.19
SiO_2	---------	---------	---------	0.44	0.47	0.86	1.75
Al_2O_3 }	0.203	0.320	0.377	0.17	0.15	0.14	0.87
Fe_2O_3 }	---------	---------	---------	---------	---------	---------	---------
Insoluble	0.540	0.390	0.815	---------	---------	---------	---------

	5a	5b	6a	6b
$CaCO_3$	94.17 to 95.67	94.03	98.39 to 95.89	93.21
$MgCO_3$	1.42 to 3.17	2.43	1.08 to 8.10	3.15
SiO_2	0.80 to 2.53	1.23	0.40 to 4.00	1.87
Al_2O_3 }	0.76 to 1.48	1.24	0.56 to 1.50	0.94
Fe_2O_3 }				
S	0.02 to 0.04	0.03	0.03 to 0.16	0.06
P	0.003 to 0.00	0.005	0.003 to 0.011	0.006

1. Shortlidge quarry, near Bellefonte, Upper bed. Hard and compact; seamed with calcite; pearl gray, with conchoidal fracture. (2, p. 307.)

2. Shortlidge quarry. Middle bed. Very hard and compact; fine grained; seamed with calcite; pearl gray, with conchoidal fracture. (2, p. 307.)

3. Shortlidge quarry. Lower bed. Hard and compact; mottled with calcite; pearl gray, with conchoidal fracture. (2, p. 307.)

4. Whiterock quarry, 1 mile southeast of Pleasant Gap. a, b and c high grade stone for lime; d, fluxing stone. Analyses by company.

5. Samples from roadside exposure about 2 miles north of east of Coburn. 8 samples analyzed. a, range; b, average. Analyzed by Cambria Steel Co.

6. Samples collected at random at Spring Mills and both east and west of there, exact location not known. 14 samples analyzed. a, range; b, average. Analyzed by H. A. Hosmer, Cambria Steel Co.

DEVONIAN AND CARBONIFEROUS LIMESTONES

Helderberg limestones. The Helderberg limestones outcrop in a narrow band extending entirely across Centre County in the Bald Eagle Valley. Throughout most of the county they are concealed by alluvial debris deposited by Bald Eagle Creek and talus that has rolled down from Bald Eagle Mountain. The limestone has been quarried in only a few places.

On either side of Unionville, near Milesburg, and about two miles south of Eagleville the Helderberg has been quarried for roads and to make agricultural lime. In the old quarry at Milesburg about 30 feet of limestone is exposed dipping 30°N. It is shaly and seems to be impure. A sample analyzed by the Cambria Steel Co. showed 2.36 per cent SiO_2. Between Milesburg and Howard there are few exposures and nothing seen that appears promising.

On account of the excellent limestone of Cambro-Ordovician age in the Nittany Valley on the other side of Bald Eagle Mountain, it is improbable that there will ever be any extensive use of the Helderberg limestone of Centre County.

Other Devonian limestones. Devonian strata, lying above the Helderberg, outcrop on the steep slopes between Bald Eagle Valley and the crest of the Allegheny Front. They are composed almost entirely of shales and sandstones. Locally, however, some calcareous phases are developed within the Oriskany, Marcellus, and Hamilton. They are everywhere very impure and have scarcely been used within the county. The best occurrence of this sort observed by the writer are some impure limestones within the Marcellus formation about 2 miles southwest of Unionville.

Carboniferous limestones. The Carboniferous strata of Centre County form the surface rocks in that portion lying northwest of the Allegheny Front. The Pocono and Mauch Chunk series are exposed near the top of the Allegheny Front, and the Pottsville and Coal Measures lie to the westward.

The Carboniferous limestones of Centre County are of little con-

sequence. Although thin, impure, and discontinuous, it is possible that they might be utilized more were it not for the close proximity of Cambro-Ordovician and Helderberg limestones of excellent quality and in large quantity in other parts of the county.

The Carboniferous limestones that have been noted are the Loyalhanna (Siliceous) of the Pocono series, and in the Allegheny group the Vanport (Ferriferous), Johnstown, Lower Freeport, and Upper Freeport. All are sparingly developed unless it be the Loyalhanna which is more of a calcareous sandstone than a siliceous limestone.

Of the Coal Measures, the Lower Freeport is best developed in the Snow Shoe Basin where it is impure and never more than 3 feet thick. The other limestones have been noted in a few localities but none of them is of any economic importance.

CALCAREOUS MARL

Mr. J. B. R. Dickey, in a brief report (4, p. 10) on some calcareous marls of the State, gives the following descriptions of some Centre County localities.

"An excellent deposit of marl has been discovered on the farm of Mrs. John M. Otto, about 2 miles east of Spring Mills. The main deposit covers about ½ acre to a depth of over four feet and extends from the main stream up a depression toward a small spring which no doubt is its source. The marl is gray, fine and free from coarse material and is covered with a few inches of loose, almost black surface soil. Analyses show a total carbonate content on an air dry basis of about 80 to 85 per cent.

"Marl in a more or less reworked condition extends down the main stream for ¼ mile, largely on the farm of Mr. Gross Shook. This reworked material contains considerable clay, is more plastic and seldom analyzes over 70 per cent. Preparations are being made to utilize and sell the marl on Mrs. Otto's farm and that on the Shook place is satisfactory for home use though somewhat more impure and difficult of distribution. Little lime has been applied in this section for many years so that the marl will supply a decided soil need."

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CHESTER COUNTY

The limestones of Chester County are found mainly in the rather narrow Chester Valley which enters from Montgomery County, a short distance southeast of Valley Forge, and continues in a direction slightly south of west entirely across the county into Lancaster County. The band of limestones is about 2 miles wide in the eastern part of the county, widens a little more than 2½ miles in the vicinity of Devault and then gradually narrows. At Downingtown it is about 1¼ miles wide, at Coatesville and westward through Pomeroy, Parkesburg and Atglen, it averages about half a mile in width. The Pennsylvania and Reading railroads follow this valley across the county, although the tracks in places are outside but close to the limestone belt. Although subordinate in commercial importance to the Schuylkill Valley, Chester Valley is generally conceded to be one of the most beautiful valleys of the county or even of the State. The limestone strata of the Chester Valley belong to the Cambrian and Ordovician periods.

South of the Chester Valley there are several isolated areas of limestones. The first is known as the Doe Run area, from the small village of Doe Run. The second and the largest continuous area is the Avondale area. A third smaller area lies about a mile south of Landenberg and smaller patches are exposed in several places, as at Brintons Bridge and northeast of Mendenhall. All of these limestones are now regarded by the geologists of the U. S. Geological Survey who have been working in this region as of pre-Cambrian age and are referred to as the Cockeysville marble of Maryland. Previously they were regarded by the same workers as of Cambro-Ordovician age and representing the same formations found in the Chester Valley. The examination of these limestones by the writer to determine their economic value revealed many points which indicate that the earlier view is the correct one. The stratigraphical relations, lithologic resemblances, and similarity of chemical composition agree very well with what has been noted in the Chester Valley. The rocks in the Doe Run, Avondale, and Landenberg areas, and similar rocks near Hockessin, Delaware show a higher degree of metamorphism than the Chester Valley limestones, but otherwise they are closely similar. However, for the sake of conformity, the author describes these limestones of southern Chester County in this volume as pre-Cambrian.

Toward the northern part of the county in the valleys of Pickering and French creeks, there are several small patches of highly-crystalline, coarse-grained marble containing numerous graphite flakes and associated with graphitic schists or gneisses. These are definitely placed in the Franklin formation which is of pre-Cambrian age.

In every section where limestones are found in Chester County, old lime kilns show how general the lime industry was at an earlier period. These small plants, mainly for the production of agricultural lime, have ceased operating but in their place there are a few large lime plants, such as those at Devault, Knickerbocker, and Planebrook, with an annual output far in excess of all of the small individual plants of former days combined. Only the best grade of stone is now used and the product is of superior quality.

Next to lime burning, the most important early use of the limestones

of Chester Valley was for building purposes. All grades of limestone were quarried for this use, but especially the marbles. These were used locally and also were sent to Philadelphia and other cities where they were used in many of the most important public buildings.

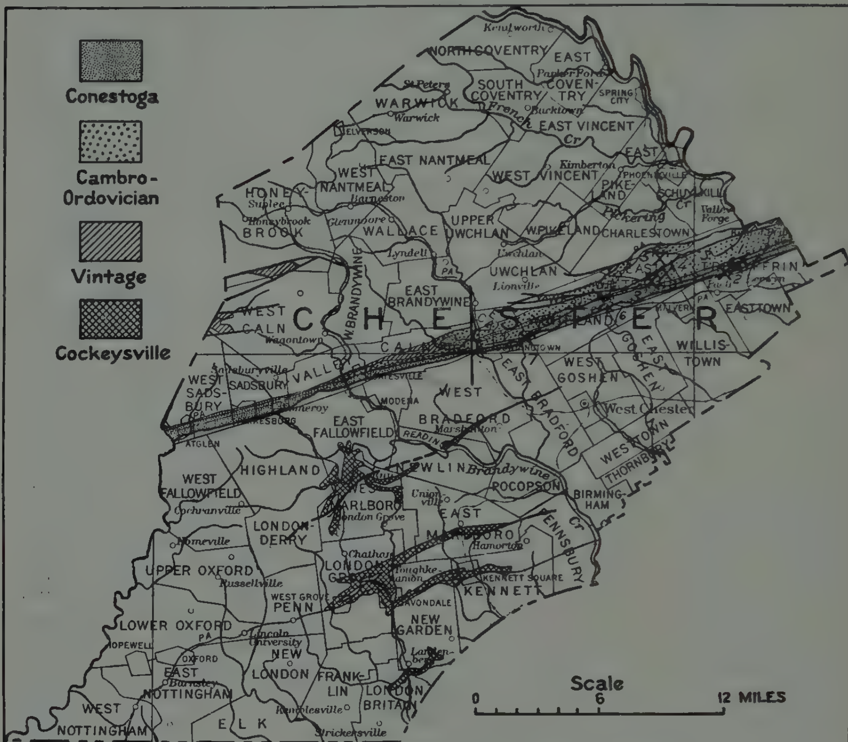

Fig. 9. Limestone areas in Chester County.

1. W. E. Johnson
2. Howellville Quarries, Inc.
3. Knickerbocker quarry of The Warner Co.
4. Samuel Given
5. Cedar Hollow quarries of The Warner Co.
6. Chester Valley Lime and Products Co.
7. J. N. Trego

Most of the marble quarried came from Chester and Montgomery counties. Near Howellville, and near Avondale, there are some large quarries where marble of fine grade was once quarried, dressed, and polished.

The most common use during recent years for the Chester County limestones has been for crushed stone. Many old quarries long abandoned have been re-opened and new ones developed to supply the demand for highway stone, especially when improved roads have been built by the State. With the exception of some of the very soft high-calcite marble, nearly all the limestones of the county are serviceable for the production of crushed stone.

PRE-CAMBRIAN LIMESTONES

Franklin limestone. The earlier pre-Cambrian formations of southeastern Pennsylvania have been divided into the following units by the geologists of the U. S. Geological Survey.

Early pre-Cambrian

Franklin limestone or marble ("coarsely crystalline, white with graphite and numerous silicate minerals.")

Pickering gneiss (banded gneiss or schist containing lenses of highly graphitic schists).

Baltimore gneiss ("sedimentary, medium to fine grained, banded gneiss with igneous intrusives. In some places thoroughly granitized.")

With the above classification, now adopted by the U. S. Geological Survey, the writer is in agreement except with regard to the separation of the Franklin limestone and Pickering gneiss as two distinct formations. Observations at several places in the Piedmont Plateau lead him to believe that they constitute a single formation similar to the Grenville formation of New York and Canada. He has discussed this problem in a previous publication (4, pp. 81-82) as follows:

"Relation of the Franklin Limestone and the Pickering Gneiss.

"In the above discussion the Franklin limestone and Pickering gneiss have been discussed as separate formations and it is probably advisable to map them as such because of the different economic uses of the two. Also in many places there seems to be a sharp line of separation between them. In other places, however, it is not possible to draw a sharp line and we have calcareous graphitic gneisses that might with equal reason be placed in either formation. We seem to have a duplication of the Grenville series of the Adirondack region where limestones, gneisses, schists, and quartzites occur in almost inextricable relationships. The workable graphite deposits of that State are contained in the Greenville rocks, mainly in the quartzites. These rocks are there believed to represent the metamorphic products of calcareous or siliceous shales. A similar explanation seems to satisfactorily explain the Franklin limestone and Pickering gneiss of Pennsylvania.

"According to the above view the two formations were formed originally as contemporaneous sediments that varied in different places. In some localities fairly pure limestone was being deposited while in adjacent regions calcareous muds or siliceous muds in which there was little or no calcareous material were accumulating. When these sediments were later metamorphosed the beds composed mainly of calcareous matter formed the rocks called the Franklin limestone; the calcareous muds gave rise to the calcareous graphitic gneisses observed in the underground workings of the Pennsylvania and Continental (Acme) mines; the muds with little calcareous matter formed the bulk of the Pickering gneiss; and the more siliceous sediments formed the quartz schists such as occur in the lower levels of the Continental (Acme) mine. The quartz schist or quartzite phase is not well represented in Pennsylvania, while in New York it forms perhaps the most important member of the Grenville series from an economic standpoint.

"On the surface the relations described above are not readily apparent because of the solution of the greater part of the calcareous matter in the originally calcareous graphitic gneiss by percolating waters. We thus have outcropping only the two kinds of materials, the relatively pure crystalline limestone and the decomposed graphitic gneiss, consequently the line of separation between them seems to be

rather sharp. Underground, however, where solution has been less effective the two grade into each other through the calcareous gneiss.

"Although bedding planes are not apparent in the Franklin limestone it seems probable that the limestone and gneiss are conformable. This conclusion is based on the fact that the limestone occurs in lenticular masses with the greatest length parallel to the strike of the gneiss beds in some localities and probably such relations would be found to exist in other places as well if it were possible to obtain the necessary data. If, then, we can prove that the two formations are conformable, with the Franklin limestone intercalated within the Pickering gneiss, we have sufficient evidence for the view expressed above that the two are of contemporaneous origin and represent merely different lithologic phases of the same series of sediments."

The Franklin limestone of Pennsylvania is best developed in Chester County where F. Bascom has mapped four small areas in the Pickering Valley and three in the valley of French Creek. In addition it has been observed in the underground workings of some of the graphite mines of Chester County as mentioned in the above quotation.

The Franklin limestone of Chester County has been quarried to a small extent for agricultural lime but the presence of considerable silicate material has caused the abandonment of all the quarries.

This limestone is very coarsely grained, in certain places the individual particles being as much as an inch in diameter. Graphite, or graphite and phlogopite, in small flakes about one-eighth inch in diameter are rather evenly distributed throughout the rock but with no regularity or apparent order of arrangement where other minerals are absent. But, in certain places, the marble is very impure and various silicates, particularly the basic ones, are present and they are arranged in approximately spherical or globular segregations varying from a few inches to several feet in diameter. The graphite associated with such segregations is usually in much larger flakes, in places as much as half an inch in diameter. Many of the flakes show distinct hexagonal outlines.

Cockeysville marble. The late pre-Cambrian formations of Chester County have been classified as follows by the geologists of the U. S. Geological Survey:

Late pre-Cambrian

Peters Creek schist ("chloritic sericitic quartz schists with chlorite muscovite schists")

Wissahickon formation ("thoroughly crystalline quartz-feldspar mica rock; gneiss and mica schist. A mica schist facies was formerly known as the Octoraro mica schist and regarded as Ordovician in age").

Cockeysville marble. ("coarsely crystalline, associated with gneiss and penetrated by pegmatites").

Setters quartzite ("occasional and limited development of quartzite beds; in some places dominantly a mica gneiss").

There are several small areas of Cockeysville marble in the southeastern part of Chester County where marble quarries were long operated. In recent years little quarrying has been done and the large openings are filled with water. The limestone is developed principally in the vicinity of Doe Run, Avondale, and Landenberg.

DESCRIPTION BY DISTRICTS

Doe Run Area. Bliss and Jonas* (3, pp. 18-19) have described the region as follows:

"In the central and southern parts of the Doe Run district limestone occurs in four distinct areas of irregular conformation. The largest area extends from Buck Run almost due south to Doe Run village, where the outcrop is pierced by an anticlinal hill of resistant quartzite. From Doe Run southwest to Green Lawn there is a continuous outcrop of limestone, and from Springdell directly south limestone joining the western flank of the quartzite occurs in a long valley that extends to the southern edge of the Doe Run district.

"On the northern and northeastern boundary of the quartzite the limestone occurs in two small but distinct outcrops at Guest's and Logan's quarries. The fourth occurrence is a narrow and irregular outcrop along a tributary of Brandywine Creek, about 2 miles northeast of Logan's quarry and 1 mile north of Upland.

"Except where it borders the quartzite the limestone of these areas is surrounded by the Wissahickon mica gneiss, thereby producing a radial and finger-like arrangement of the surface outcrops which is particularly striking."

About one mile north of Doe Run there is an old quarry, long abandoned, and now largely filled with water. The stone is a white or banded marble with light blue streaks. Some of it is extremely sugary in appearance. Some streaks appear to be high in silica but most of the stone exposed seems to be a fairly pure non-magnesian coarsely crystalline marble. The beds strike N.27°W. and dip almost vertically. A thickness of about 50 feet of stone is exposed. The stone was burned for lime.

About one-fourth mile northwest of Doe Run there is a similar old abandoned quarry but here there seems to be considerable magnesian rock interbedded with the low-magnesian marble and streaks in which there are abundant flakes of mica. Some of the coarsely crystalline dolomite has disintegrated to form a sand.

Just south of Doe Run Station and north of Springdell there are 3 abandoned quarries, one of which covers a large area. In the large one, the strike and dip vary in different portions of the opening and there are many small folds but on an average the strike is about N73°E., dip 15°SE. Several varieties of stone are exposed. Most of it is a crystalline white to gray marble. Some beds appear to be high in both magnesia and silica and there are some interbedded micaceous limestones and mica schists. The stone resembles some of the Conestoga limestones of Chester Valley and suggests the correlation advanced above. By working these quarries with care, doubtless several grades of desirable stone might be obtained here. The stone was burned for lime.

About 1½ miles southeast of Doe Run there is a quarry in a detached area of limestone showing about 35 feet of coarse-grained crystalline dolomite first worked for lime. This is known as Logan's quarry. About 10 years ago, the present owner, Saint Amour Co., ground about 500 tons of the raw stone for farm use. The good stone is overlain by about 15 feet of sandy stone. About 1¾ miles farther

* The limestone now considered pre-Cambrian in age was originally considered Paleozoic and is so-called in the report from which these quotations are taken.

east but in the same area of limestone, there is a fairly large quarry in which the strata are badly twisted and folded. On an average they strike about N58°E. and dip 55°SE. The quarry exposes both dolomitic and low-magnesian marbles interbedded. The stone was burned for lime.

In another detached area of limestone about one mile north of the last mentioned quarry and about 3 miles east of Doe Run, there are 2 old quarries containing both low and high magnesian white to gray marble interbedded. There are numerous streaks of mica within the marble. The beds dip to the southeast at angles of 30° to 35°.

By way of summary it may be said that the Doe Run limestones are of various types and so interbedded that it would require careful investigation by trenching and drilling to determine the possibility of opening a quarry to obtain a single variety of stone.

Avondale Area. The largest continuous area of Cockeysville marble is situated in the vicinity of Avondale. Bliss and Jonas in their report describe the area as follows (3 p. 18).

"In the Avondale district the limestone occupies the valley of White Clay Creek about Avondale and to the north. The areas are not more than half a mile wide and are very irregular. The northern area extends southwestward for about 5 miles from the center of the eastern border of the Coatesville quadrangle; then it turns south and curves about a hill of mica gneiss which lies north of Westgrove; from that point it extends southward through Baker and southeastward to Avondale, where it connects with two belts of the formation—one from the east along Trout Run and the other from the north.

"As there are no natural outcrops of the limestone, its extent is best determined by the soil it makes—a red clay such as is formed by the weathering of a magnesian lime rock. It is exposed for the most part in abandoned quarries which are partly filled with water; the rock forming the walls may be fresh or partly disintegrated into calcareous sand or almost entirely covered by a talus of soil. In the region of Baker and Avondale there are large quarries which are now being operated in this rock and which furnish valuable marble and building stone.

"The strike of the formation ranges between N.60°E. and N.70°E. The direction of dip is generally southeast, the only prominent exception being a northwest dip found in a small quarry just north of Westgrove. The angle of dip is low, varying from 20° to 25°.

"Where pure the fresh rock is a medium-grained, highly crystalline, lustrous, white, saccharoidal marble, characterized by the abundant development of various accessory minerals. Phlogopite in glistening amber-brown scales is in some places so plentiful that, on planes parallel to the bedding, the rock may appear to be composed almost entirely of mica. Where the phlogopite occurs in smaller flakes it gives the rock a variegated appearance, which has won for it the name "bastard granite". Biotite, muscovite, tourmaline in large black crystals, magnetite, apatite, and pyrite are common accessory minerals.

"Evidences of pressure seen in the thin section are twinning of the calcite crystals, granulation, and undulatory extinction of the quartz, which occurs in interlocking areas forming a mosaic with calcite.

"In the Avondale district the thickness of the limestone, which does

not exceed 1,000 feet, represents only part of the original thickness; the remainder has been removed by erosion."

In 1931 no quarries were in operation in the Avondale area, but in the past a great deal of fine white marble was produced here as well as lime. Along the south side of Trout Creek about half a mile northwest of Avondale there has long been extensive quarrying. The last work done here was about 10 years ago when a Baltimore company worked the quarries for building stone and pulverized the fine stone. Along this ridge there are several openings and old lime kilns. The quarry is now largely filled with water. It is said that a 90-foot face was worked. There are several grades of stone in the quarry. Perhaps the most common is a very uniform coarse-grained white marble with the individual particles about one-eighth inch in diameter. Other bands contain little to much phlogopite mica. Some bands are practically mica schists in parallel layers interbedded with the pure marble. Some of the marble is gray to light blue generally observed as banded with the white variety. Much of the stone is very handsome when dressed and polished. Most of the stone is fairly low in magnesia but rather high in silica because of the mica.

Just north of Baker, there is a very large quarry now filled with water to such an extent that only at one side can the marble be seen. The depth of the quarry is not known but it is reported to be 150 feet. The quarry was formerly worked for both building marble and to get stone for burning. There are 8 old lime kilns near the quarry. In 1928 a small amount of stone was quarried here from the ledges above water level to obtain stone for a bank building in Allentown. Some was also being shipped to Media. As in the previous quarry described, the stone in this quarry varies from white to gray, free from phlogopite mica, to coarse marble well filled with the golden yellowish brown flakes of mica. It is said that there is one band running through the quarry about 20 feet in thickness that is practically all mica. The stone varies greatly in the amount of magnesia and silica. Whether there is a sufficient thickness of low magnesia rock to be worked commercially has not been determined. It appears probable that drilling might discover such masses of good stone.

One mile northwest of Baker, an old quarry now almost entirely filled with water appears to have a good quality of stone, judging from the limited exposures above the water's edge.

Just north of West Grove there are two small abandoned quarries filled with water. One of them shows about a foot of decomposed sugary marble above the water but the other one has no rock exposed. An old kiln stands near by.

It is to be regretted that these quarries that once furnished high grade marble should now be idle and one wonders whether they might not be again worked with profit to furnish stone for buildings and by working certain parts obtain stone satisfactory for high grade lime, for whiting, for flux, for cement, etc.

Landenberg Area. A little over a mile south of Landenberg is an isolated narrow band of Cockeysville marble extending in a northeast-southwest direction for a distance of about 2½ miles. Near the southwestern extremity of this band, about 1¾ miles south of Landenberg there are two long-abandoned quarries located near the top of the hill. There are old lime kilns near by. The stone is coarsely crystalline

and in alternating bands highly dolomitic and low in magnesia. Near the surface the stone is decomposed to such an extent that it can be crumbled in the hand. The exposures are limited owing to the slumping of the surface soil.

About 1¼ miles to the northeast, near the junction of Walnut Run and Broad Run there are two old quarries that exposed about 25 feet of badly decomposed marble. Some bands are almost free of mica and appear to be of good grade.

The reports of the First and Second Geological Surveys of Pennsylvania contain descriptions of the Cockeysville marble areas as they were known at the time those reports were published.

Analyses of Cockeysville marble

	1	2	3	4	5
$CaCO_3$	94.27	93.31	84.07	73.48	97.50
$MgCO_3$	1.56	1.85	11.14	15.59	.75
$Fe_2O_3+Al_2O_3$	.26	.75	....	....	1.04
Insoluble	3.91	4.84	4.76	10.76	.84

All samples from quarry along Philadelphia, Baltimore and Washington Central Branch of Pennsylvania R. R. northwest of Avondale. Nos. 1, 2 and 5, white stone, 3 blue stone, 4 gray stone. Analyses 1, 2 and 3 made by Booth, Blair & Garrett, 4 by Wellman Iron and Steel Co., and 5 by Bethlehem Steel Co.

CAMBRO-ORDOVICIAN LIMESTONES

The limestones designated as Cambro-Ordovician are confined entirely to Chester Valley as mentioned on a previous page. In the eastern part of the valley included within the county, there are three fairly distinct bands of stone that can be differentiated and occasionally four, as described in Montgomery County. These have not been as well differentiated as in Lancaster County so that the descriptions are therefore generalized.

The oldest limestones occupy the northern part of the valley, are of Cambrian age, and rest upon the Chickies quartzite which forms the northern bounding hills. These limestones represent the Cambrian strata which in Lancaster County and elsewhere have been separated into the Tomstown (Vintage, Kinzers and Ledger), Elbrook, and Conococheague formations. They are prevailingly dolomitic, varying greatly in the amount of magnesia which they contain. Practically no low-magnesian strata are present in the entire thickness, which is probably as much as 2,000 feet, perhaps more. Further, there is a rather definite band near the north part of the valley that contains high-magnesian (over 40% $MgCO_3$) stone low in silica. This band which has long been extensively quarried at Cedar Hollow is believed to be continuous with that exposed near Bridgeport and Plymouth Meeting in Montgomery County. Underlying and also overlying this band of high quality dolomite, there are other dolomitic limestones of good grade but in thinner bands, interbedded with shaly and siliceous strata. This band of Cambrian dolomitic limestones enters from Montgomery County and can be traced westward a short distance beyond Cedar Hollow. It may possibly extend through the north part of the valley to the vicinity of Exton, although this appears to be rather unlikely. How far the band of high grade dolomite extends westward from Cedar Hollow will probably not be definitely

known until considerable drilling is done, as the limited outcrops fail to furnish sufficient information on which to base a conclusion.

The second band of stone in Chester Valley occupies more or less the central part of the valley from the Montgomery County line to a point probably near Planebrook or Exton and the northern part of the limestone valley from there westward a short distance beyond Downingtown. From Coatesville westward to the Lancaster County line it appears to be lacking. The strata in this band, aggregating from 1000 to 2000 feet in thickness, belong to the Beekmantown formation. They consist of interbedded low-and high-magnesian rocks. In general, the high-magnesian variety predominates so that occasional quarries, such as the old Knickerbocker quarries near Mill Lane, have been able to obtain a workable thickness of fair grade stone. Going upward stratigraphically in the formation and southward in the valley, the proportion of interbedded low-magnesian stone increases but nowhere in the region within the formation does it appear probable that high-calcium stone of workable thickness on any considerable scale will be found. Many exposures can be found where picked samples will analyze over 90 per cent $CaCO_3$ and no more than 2 or 3 per cent SiO_2 or over 40 per cent $MgCO_3$ and low in SiO_2. Careful investigations must be made before opening any quarries in this section if a more or less exact chemical composition is demanded.

The third definite band of stone recognized in Chester Valley occupies the south part of the valley from the Montgomery County line to a point somewhat beyond Downingtown and the entire limestone valley from there westward to the Lancaster County line. This constitutes the Conestoga formation of Ordovician age. This band has several types of stone, the most abundant of which is a micaceous limestone. The greater part of the rock is a crystalline gray marble but running through it in parallel bands are thin laminae of sericite mica along which planes the rock readily splits. The flat surfaces of the broken rocks coated with overlapping mica flakes resemble mica schist but examination of the jagged broken edges shows the true character of the stone. This stone is generally low in magnesia but fairly high in silica because of the abundance of mica.

Interbedded with these micaceous limestones and more abundant near the base are thin to massive, crystalline, high-calcium marble and high grade dolomite. Some of these marble and dolomite bands or lenses are continuous for some distance but others are extremely local. Near the base of this third series discontinuous lenses of mica schists are interbedded with these other rocks. These schist lenses in places extend for distances of several miles and are up to 300 feet thick or more. In most places these mica schist strata form conspicuous ridges through the valley because of their resistance to erosion.

The micaceous limestones become more micaceous near the southern part of the valley and seem to pass without any sharp break into the overlying mica schists which constitute the hills bordering the Chester Valley on the south. The writer regards these bounding mica schists as of Ordovician age and correlates them with the Martinsburg formation of the Lehigh Valley. Some geologists believe these mica schists to belong to the pre-Cambrian and to have been thrust over the bordering limestones by a great fault.

STRUCTURE OF THE CHESTER VALLEY

The general structure of the Chester Valley is rather simple but in detail it is extremely complicated by numerous folds and faults. The various formations outcrop in fairly parallel bands that have the same trend as the valley itself. The Cambrian quartzites which form the northern boundary of the valley are the oldest rocks concerned. They dip to the south-southeast and underlie the entire valley but at great depth in the southern portion. The basal dolomitic limestones outcropping in the northern part of the eastern half of the valley rest conformably on these quartzites. With everywhere the same south-southeast dip these basal beds of Cambrian age disappear toward the central part of the valley by dipping beneath the Beekmantown (Ordovician) interbedded limestones and dolomites and they in turn dipping beneath the Conestoga (Ordovician) micaceous limestones and interbedded marble, dolomite and mica schist lenses in the southern part of the valley. The uppermost limestones, as stated elsewhere, are believed by the writer to pass conformably beneath the mica schists of the hills bounding the valley on the south. Thus in crossing the valley from north to south one continuously passes over the outcrops of older to younger beds.

The detailed structure can not be discussed so well because of local folds and faults, that are abundant in some sections, but not in all portions of the valley. In most places these faults as now known do not have great displacement and the folds also generally do not involve great thicknesses of the strata. This, of course, does not refer to the major fold by which practically all the beds originally deposited in horizontal layers have now been changed to the general south-southeast dip of 30° to 85° or even vertical in places. Any one desirous of utilizing the limestones of the valley should make a careful investigation of the structural conditions. In the progress of this study the writer has found that some of the quarry companies operating here did not understand the structural problems they were encountering and how to take advantage of them or to minimize the obstacles which they presented.

More of these limestones have been quarried for lime than for any other purpose. Most of the quarries are small, were worked for local use, and are now idle. Several different kinds of stone were formerly worked in the valley but at present little attention is given to any other than the low-silica dolomites which are used for lime, flux, crushed stone, and in a few places for the extraction of magnesium carbonate, and the hard rocks of any composition used for crushed stone. Where used for lime the rock is broken to secure blocks 10 to 12 inches in diameter (one man size) that are used for lime burning; the next size smaller is suitable for flux, and the fragments under 2 or 3 inches are used for concrete and ballast. When the demand for any one kind is particularly good, special efforts are made to produce as much of the desired size as possible. Generally it is not profitable to produce the smaller sizes.

The demand in recent years for road stone has resulted in several quarries formerly used for lime being changed or re-opened to supply crushed stone. These are most important in the Howellville region. The various companies operating in the region have made detailed investigations to find desirable quarry locations. The obstacles en-

countered are heavy overburden of clay and rotten rock, interbedded strata of high silica content, clay seams or pockets, and contorted or shattered stone. For profitable operation the stone must be near the railroad and the topographic situation such as to permit ready operation and easy drainage. A number of quarries have been abandoned because of encountering one or more undesirable conditions.

DESCRIPTION BY DISTRICTS

There are so many places in the Chester Valley where limestones of different qualities have been quarried that it is not feasible to attempt to mention all or even the greater portion of them. Nevertheless, it is well appreciated that some of these long idle quarries may eventually form the basis for active and prosperous limestone operations. In general only those areas where limestone quarrying is now in process will be described.

Howellville Area. There has long been extensive quarrying in the Howellville region. At an early period it seems that some ornamental marble was quarried here although nearly all was used for lime. A number of old lime kilns can still be seen about the active and abandoned quarries. At present only crushed stone is being produced in this vicinity.

Just east of the Howellville crossroads there are a number of old stone houses along the highway which were used by the workers of 3 quarries lying a short distance to the south. A large battery of old lime kilns now falling into ruins is located near the quarries. The two south quarries are in the same line on either side of a small stream. The western quarry is almost entirely filled with water which is said to be quite deep and now serves as the swimming hole for the boys of the neighborhood. The eastern one contains but little water. On the south wall of these quarries there is mica schist. The strata dip very steeply, 84°S. or more, and are almost vertical in places. They consist of a series of interbedded, fine-grained dolomite and low-magnesian marble. The overburden is rather thin but in certain beds is deep because of the decomposition of these particular strata. Both quarries were worked approximately to property lines. The third quarry lying somewhat to the north contains the same mixture of low and high magnesian stones interbedded. The clay obstacles seems to have been here a serious one.

On the north side of the highway and slightly farther west is the quarry of W. E. Johnson, long worked by Samuel Given. On the south side of the opening close to the highway, there is a band about 35 feet wide where the stone is low in magnesia. For a long time this was worked separately and the material burned for lime. In recent years, however, all of the quarry output goes together for crushed stone. The bulk of the stone is dolomitic and satisfactory for crushed stone, but not sufficiently pure for a good grade of lime. At times considerable building stone has been gotten out also. It is a common practice for companies having any demand for building stone to put aside those blocks that are of convenient size and shape and send the balance to the crushers. In general the strata have approximately an east-west strike and dip about 70°S. In the east side of the quarry there is a well-pronounced, tightly-compressed local fold.

The largest quarry in the Howellville region is that of the Howellville Quarries, Inc. (formerly E. J. Lavino & Co.). This quarry has been worked for many years and contains several grades of stone. Lime was formerly burned here, fluxing stone has been produced, and agricultural pulverized limestone has been made, but now the entire output is crushed stone. The quarry is bounded on the south by a lens of mica schist which is at times a serious obstacle because portions of this useless material break off and fall on the good stone. All of the beds dip steeply to the south at an average angle of perhaps 80° to 85°. Near the schist there is some high grade low-silica dolomite, light buff to white in color, dense and fine grained. Near the north portion of the quarry there is some coarsely crystalline white to gray marble, low in magnesia. The bulk of the stone is dolomitic but with interbedded strata high in calcium. The clay overburden has been heavy and much will have to be removed if the quarry is extended either to the north or west. The buildings and road limit the extension eastward and the mica schist southward. From what has been stated, it is apparent that no analyses will entirely represent the various types of stone. The following analyses furnished by the company several years ago may be regarded as fairly typical.

Stone from Howellville Quarries, Inc., Howellville

$CaCO_3$	72.07	54.37
$MgCO_3$	22.01	35.94
SiO_2	3.96	5.80
$Al_2O_3+Fe_2O_3$	0.70	3.84

Mill Lane Area. The Knickerbocker Lime Co. (now a part of the Warner Co.) long worked quarries extensively at Mill Lane, but these are now idle; the valuable lime plant is still in operation, supplied with stone from the Cedar Hollow quarries. The company has worked quarries at a number of places along both sides of Valley Creek. On the north side there is an almost continuous opening for more than a mile in the same beds. Their No. 4 quarry on the southeast side of the creek is in the same strike. Another quarry (No. 6), known as the Holland Meadows quarry, lies about one mile to the northeast and is in a different series of beds. In the main series the beds quarried consist of low-silica dolomite and approximate 100 feet in thickness. They have a variable but always steep dip to the south. Some good stone may still be quarried here but in most of the openings it is no longer practicable to work the good grade of stone and their high grade lime is made from the stone brought from the Cedar Hollow quarry. Some of the poorer grade stone of the old quarries is being worked for road metal.

Samuel Given is working a quarry (known as the Dougherty quarry) just northeast of the most easterly of the old Knickerbocker quarries for crushed stone. Some old lime kilns show that the stone was formerly burned for lime. The stone is dolomitic and similar to the Knickerbocker material. The beds dip to the south at angles of 50° to 70° with the strike approximately east-west. Some layers of excellent light buff dense dolomite are exposed in the quarry. Some of this stone was shipped to the Johns-Manville Co. for the extraction of magnesia. An average of 11 analyses furnished by the company is as follows:

Analysis of stone from Given quarry, Mill Lane

SiO_2	0.96
$Al_2O_3+Fe_2O_3$	0.75
Calcium carbonate	54.26
Magnesium carbonate	43.58

Cedar Hollow Area. The most extensive limestone quarrying operations in Chester County are those of the Warner Co. at Cedar Hollow, near Devault. The present quarry represents several consolidations of quarries by which the one company now owns all of the ledge of fine grade dolomite in the section and has a continuous quarry opening 3000 feet in length in an east-west direction and 800 feet wide in the widest portion. This quarry lies south of the road and kilns. Another smaller detached quarry is located to the north.

The rock is a low-silica dolomite. The beds dip from 45° to 55°S. with an approximate east-west strike. There are two bands of good stone, the northerly one with a surface outcrop about 500 feet wide and the southerly one about 150 feet wide. They are separated by a band of high-silica stone that is now used for crushed stone. The best grade stone is the light buff or cream-colored, dense dolomite that is very low in silica. A gray to slightly mottled dolomite is almost as good. The higher silica variety is rather dark and harder. The dolomite layers have been greatly jointed and in places so uniformly that the joints resemble bedding planes.

Quarrying is being carried on in different parts but the bulk of the stone now comes from new workings in the quarry floor. This new depth is 60 feet below the roadbed and plant. An upper older level with about 50 feet face is being extended southward. The company has an enormous body of stone of high and uniform grade.

The stone is used for a variety of purposes. There are 17 lime kilns near the quarry and 11 at the old Knickerbocker plant about 3 miles away that are supplied with one-man size (10 to 12 inches) blocks. The kilns are of different capacities. There is a rotary kiln, not recently in use, where the smaller sizes were burned. Blocks of about the same size as burned for lime are sold to some of the magnesia companies for the extraction of magnesia. The finer sizes and the siliceous varieties are crushed in a modern crushing plant with a capacity of 150 tons per hour. Pulverized limestone is also made for various purposes. The lime made here is marketed as lump or hydrated lime. The plant throughout is well equipped and capable of producing high grade products.

Planebrook Area. In October 1930 the Chester Valley Lime and Products Co. opened a new quarry just west of Planebrook P. O. near an old limestone quarry worked many years ago for lime. The surface clay was used for the manufacture of brick. An emery wheel plant was operated at this place for a number of years. The new quarry is now only about 40 feet deep and approximately 125 feet in diameter. The dolomite occurs in fairly massive beds, dipping about 45°S. There is a little interbedded shaly material. The surficial clay runs down in some bad clay pockets and some of the stone has become discolored. This stone is used for crushed stone and the clean stone of good quality burned for lime. Four kilns have been erected. The crusher has a capacity of 200 tons per day.

An analysis of a sample sent to the Bureau of Chemistry of the Pennsylvania Department of Agriculture is as follows:

Analysis of stone from Planebrook

$CaCO_3$	54.09
$MgCO_3$	44.11
Acid insoluble matter	2.49

Ackworth Area. Rogers in his report on the "Geology of Pennsylvania", Vol. 1, p. 215, described a marble quarry near Ackworth (now Whitford P. O.) as it was in 1853. His description is as follows:

"A little south of the Valley Turnpike, about three and a half miles E. of Downingtown, is the extensive quarry of superior white marble which has for many years supplied Philadelphia with the beautiful articles employed in so many of its public and private edifices. It is on the farm of Mr. John R. Thomas. The beds on this quarry are slightly contorted. The portion worked for the marble separates into two bands. The rock occurs in massive beds, chiefly white, with sometimes a bluish tinge, and is quarried with great facility. It has been much used in the construction of the Girard College and other public buildings which adorn Philadelphia and the neighboring towns. This marble is converted into a good lime, but its crystalline or granular structure causes it to crumble in the kiln, making it a little difficult to manage. The lime from this variety is much esteemed by masons, being sold in Philadelphia under the name of *Fish-egg Lime.*"

This quarry and another near by have long been idle and the larger one is now filled with water.

A short distance east of this quarry described by Rogers, J. N. Trego has recently re-opened a quarry for crushed stone. There is an old lime kiln near by. The quarry shows interbedded high calcium marble and dolomite. A short time ago an option was secured on the property and it was prospected by drilling to determine whether the quality of stone obtainable would be suitable for the manufacture of Portland cement. The results obtained were not favorable as the percentage of magnesia was entirely too high.

Downingtown Area. In the west edge of Downingtown, close to the Pennsylvania Railroad tracks, there is an old quarry in the Conestoga formation. The micaceous limestone appears in the south side of the quarry, but most of the opening shows interbedded dolomite and marble dipping steeply to the south, almost vertical, and striking nearly east and west.

One mile farther west, an old quarry in micaceous limestone shows that this rock was once used.

A short distance to the west on the north side of the highway and railroad, there is an old quarry in almost vertical dolomite beds, and two lime kilns.

Coatesville-Pomeroy-Parkesburg-Atglen Area. From Coatesville westward to the Lancaster County line all of the limestone belongs to the Conestoga formation. These limestones have been quarried in a few places but not for many years. They consist of micaceous limestones with some dolomites and marbles. There is little stone of promise in this area.

In the west part of Coatesville there are fine exposures of micaceous limestone, some of which seems to have once been quarried. There

is also a quarry in the same vicinity that shows only dolomitic beds. The micaceous limestone was once quarried on the north side of the highway a little over a mile west of Coatesville. The strata strike N.83°E. and dip 81°SE.

On the north side of the highway one-fourth mile east of Pomeroy a mixture of good grade limestone and micaceous stone was once quarried.

One-fourth mile west of Stottsville there is an old opening where it is said that some marble was once quarried. An old lime kiln standing near by indicates that part of the stone was burned.

About half a mile southeast of Parkesburg there are 3 old quarries. The largest one, which is about 300 by 175 feet and 35 feet above the level of the water, reveals some nice looking marble. The strata strike east-west and are practically vertical. The other quarries are in micaceous limestone, some of which appears to be of good grade but the other is decidedly poor. A lime kiln stands near one of the openings.

A small quarry of no significance is located about one-fourth mile southwest of Atglen.

Additional analyses of Chester County Cambro-Ordovician limestones

	1	2	3	4	5a	5b
$CaCO_3$	52.13	55.01	55.18–54.91	54.27–55.01–54.13	54.01	54.01
$MgCO_3$	44.26	42.96	42.32–41.90	42.69–42.32–43.03	42.69	42.54
SiO_2	1.53	1.50	1.58– 2.12	1.78– 1.72– 1.51	0.85	1.63
$Fe_2O_3+Al_2O_3$	1.82	0.72	1.00– 1.12	0.82– 0.80– 1.27	0.44	0.57

1. No. 6 (Holland's Meadow) quarry of Knickerbocker Lime Co. (now a part of The Warner Co.), 1½ miles northeast of Mill Lane. Analysis by company.
2. No. 3 quarry of Knickerbocker Lime Co. (now a part of The Warner Co.), 1 mile east of Mill Lane. Analysis by the company.
3. West end of quarry No. 1, Knickerbocker Lime Co. (now a part of The Warner Co.), Mill Lane. Analyses by company.
4. Knickerbocker Lime Co's (now a part of The Warner Co.) Cedar Hollow quarry, ½ mile SE. of Devault. Analyses by company.
5. Quarries of The Warner Co. at Cedar Hollow, ½ mile SE. of Devault. a. Quarry No. 6, average of 10 analyses. b. Whiteland quarry. Analyses by company.

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CLARION COUNTY

Although limestone occurs in a great many places in Clarion County, no important limestone industries have been developed. Small quarries have been opened in scores of places but practically all of these have been small operations just sufficient to furnish enough stone for small lime kilns or iron blast furnaces. At one time farmers throughout the region obtained limestone from outcrops along the hillsides and burned their own lime for agricultural use. Also considerable limestone was required by the small blast furnaces scattered through the county. The ore for most of these furnaces was the carbonate of iron ore bed or its oxidized limonitic product that directly overlies the Vanport (Ferriferous) limestone. Although this layer was seldom over 1½ feet in thickness and in most places was much less, it was extensively worked. Some similar low grade iron ores at other horizons were worked in a few localities. All iron ore quarrying or mining was abandoned long ago and all the blast furnaces are in ruins.

In recent years a new use for the local limestones has been developed which seems to give some promise. This is the use of pulverized raw limestone instead of lime on the soil. Already in a few places in the county this has been done and it is probable that the pulverizing business will increase, as satisfactory results have been obtained.

Four different named limestones have been noted as outcropping beds within the county, all included within the Allegheny group. In order of age, these are the Vanport (Ferriferous), Johnstown, Lower Freeport, and Upper Freeport. Of these, the first only is of real importance because of its wide development, particularly in the southern half of the county, its uniformity and its good quality, whereas the others, although used in a number of localities at different times, are of minor value. Except in the extreme southwestern corner of the county, the Vanport is much thinner and consequently much less valuable than in the adjoining counties to the west and south so that there have never been any large scale operations such as those in Armstrong, Butler and Lawrence counties.

Generalized section of the rocks exposed in Clarion County

	Maximum thickness in feet
Conemaugh group	230
Mahoning sandstone (upper part)	
Mahoning coal	
Mahoning sandstone (lower part)	
Allegheny group	370
Upper Freeport coal	
Upper Freeport clay	
Upper Freeport limestone	
Lower Freeport coal	
Lower Freeport clay	
Lower Freeport limestone	
Freeport sandstone	
Upper Kittanning coal	
Johnstown limestone	
Upper Kittaning clay	
Thin coal	
Middle Kittanning coal	
Middle Kittanning clay	
Lower Kittanning coal	
Lower Kittanning clay	
Kittanning sandstone	
Vanport limestone	
Upper Clarion coal	
Upper Clarion clay	
Lower Clarion coal	
Lower Clarion clay	
Clarion sandstone	
Craigsville coal	
Brookville coal	
Pottsville series	130
Homewood sandstone	
Mercer shale	
Connoquenessing sandstone	
Pocono series	310
Burgoon sandstone	
Cuyahoga (Meadville) shale	35

The strata in Clarion County are in level or gently dipping beds. Several extensive gentle folds trending northeast and southwest cross the county; the beds in the folds all rise to the north. Erosion has removed large amounts of the original deposits so that one now finds the later (younger) beds in the southern part of the county and the older in the northern part.

LIMESTONES OF THE ALLEGHENY GROUP

Vanport (Ferriferous) limestone. The Vanport limestone is well developed in the southern and extreme western portions of Clarion County where it has furnished stone for agricultural and building lime, pulverized agricultural limestone, fluxing stone for the iron ore furnaces once common, and to a lesser degree for structural purposes. The outcrops can be traced along the sides of the stream valleys for long distances. It is stated that the outcrops of his bed within Clarion County aggregate 450 miles.

The Vanport limestone, sometimes designated "Ferriferous" limestone, is one of the most persistent and best known strata of western Pennsylvania. It takes its name from the town of Vanport, Beaver County, Pennsylvania, where it is typically developed. Wherever it is found it is a valuable key rock for identifying other rocks and for determining the position of oil and gas sands. The top of the limestone is 110 to 130 feet above the base of the Allegheny formation, the average distance being about 120 feet.

Most of the beds between the Clarion coals and the Vanport limestone are dark-drab shale containing numerous iron nodules. In much of the area a coarse sandstone occurs immediately below the Vanport. It is generally 1 or 2 feet thick, but locally is much thicker. In many places there is no sandstone below the Vanport, and it lies almost immediately upon the Upper Clarion coal.

In quality the Vanport limestone is very pure, an analysis showing about 95 per cent calcium carbonate, with little magnesium. The rock is dark gray and fossiliferous. Brachiopods and fragments of crinoid stems are abundant, and corals, pelecypods, and gastropods are common. All of these fossils indicate that the rock is of marine origin. The average thickness of the limestone in the southeastern part of the county (Clarion Quadrangle) is about 7 feet. Drillers report 10 feet of limestone in places, but none of the sections noted in quarries exceed 8 feet. In the southwestern part of the county the average thickness of the Vanport is about 10 feet and this increases to 20 feet south of Callenburg. In the northeast quarter of the county, the Vanport is absent except on the tops of a few of the highest hills. Whether no calcareous material was ever deposited there, or whether it was deposited and eroded before the succeeding sediments were laid down, is uncertain.

The Vanport outcrop girdles all the hills near Fryburg. It ranges from 5 to 6 feet in thickness and is favorably situated for quarrying over a quite large area. It comes out in thin slabs, with characteristically irregular faces. In Farmington Township the Vanport outcrops near the tops of three hills at Scotch Hills covering an aggregate area of 150 to 200 acres. It is 4 to 5 feet thick.

The Vanport is found in all the higher hills of Ashland Township. In the eastern part of the township, it is from 6 to 6½ feet thick.

In places it is so near the tops of hills that the cover is very thin and large amounts can be obtained easily. Here it has been extensively quarried for lime. In Elk Township it has largely been removed by erosion north of Shippenville.

It is developed in the vicinity of Lucinda where the ore overlying the limestone was at one time extensively worked. In Paint Township it is nearly or quite absent and in Highland Township is sparingly developed except near Helen Furnace. It seems to be absent in Mill Creek Township. South of Salem some hill summits retain a small amount of the Vanport. In addition there is a small tract in the northwestern corner of Salem Township but over most of the township it has been removed.

In the northeastern part of Richland Township it lies near the tops of hills with so little overburden that it can be easily quarried. It ranges in thickness from 4 to 7 feet. It readily separates into slabs from half an inch to 3 inches in thickness. It has been quarried at St. Petersburg where it is about 7 feet thick. The Vanport was at one time actively quarried for lime near Edenburg where it is about 7 feet thick.

In Clarion Township it should be extensively developed but in most places it is lacking. A specimen from this locality has been analyzed and appears on a later page.

In Perry Township the Vanport is almost continuously developed, outcropping along the hillsides. It varies from 12 to 20 feet in thickness. An analysis is given below. The same situation prevails in Licking Township, where both the limestone and associated iron ore were once worked for local furnaces. They outcrop in the hills some distance back from Clarion River.

In Toby Township, the Vanport has a wide outcrop and has been quarried in many places, especially in the valleys of Cherry Run and Wildcat Run.

The Vanport limestone and iron ore were formerly worked at several different points in Piney Township.

The Vanport throughout Monroe Township is about 6 feet thick and has been quarried in several places. In Limestone Township, it is known to be at least 5 feet thick, perhaps more.

In Brady Township, the Vanport is about 15 feet thick with 6 to 10 inches of overlying iron ore, both of which have been quarried.

In Madison Township it has been quarried extensively especially near Lawsonham and Riversburg.

It is accessible along all the larger streams in Porter Township. From New Bethlehem northward along Leisure Run it can be seen almost continuously for a distance of five miles. Along this stream, Long Run, and Leatherwood Creek, the limestone and associated iron ore were widely quarried and used in old iron furnaces.

In Red Bank Township it has been quarried along Middle Run, Town Run, and Pine Creek. It ranges from 4 to 7 feet thick. Along Town Run about 2 miles north of Hawthorne the Vanport has a thickness of 5½ feet. It shows the fossils characteristic of the formation. A layer of iron ore about 6 inches thick overlies the limestone. Where the Brookville-New Bethlehem road crosses Town Run, the Vanport is prominently exposed in the stream bed. About one mile north of Mayport along Pine Run, the same limestone has been quarried re-

cently by E. V. Minnich to burn for local use. A similar operation is located one mile south of Shannondale where the Vanport is 6 to 7 feet thick with a 15-foot overburden.

Irwin E. Switzer has quarried the Vanport from three pits on his farm about 1½ miles south of Frogtown where it shows its typical character. The bed is 6 feet thick. The upper part is rather shaly. Nodules or thin layers of chert and a thin layer of iron ore are present above the limestone. The stone has been pulverized and sold for agricultural purposes in recent years but it has scarcely been profitable. It is ground in a Day pulverizer to 80 per cent through a 100-mesh screen. As much as 300 tons have been sold in one season.

Analyses of Vanport limestone in Clarion County

	1	2	3	4
$CaCO_3$	95.232	95.532	95.196	96.428
$MgCO_3$	.407	.930	1.265	1.202
SiO_2	2.190	1.960	1.780	1.110
$Al_2O_3+Fe_2O_3$	1.310	1.050	1.529	.867
P	.061	.070	.081	.023

1. Vanport limestone. On Long Run, Porter Township. Bed 5 to 6 feet thick, with 9 inches carbonate ore overlying. Brittle; more or less stained with ferric oxide; generally pearl gray. (3, p. 87)
2. Vanport limestone. Hindmans quarry, Clarion township. Fine grained; mottled with calcite; rather brittle, bluish gray. (3, p. 87)
3. Vanport limestone. Sligo furnace, Piney township. Fine grained; rather tough, stained with ferric oxide; light bluish gray. (3, p. 87)
4. Vanport limestone. Barger quarry, Perry township. Rather coarse-grained: mottled with calcite; bluish gray. (3, p. 87)

Johnstown limestone. The Johnstown limestone is practically absent from Clarion County. Chance (Report VV, pp. 43-44) reports having seen it on Middle Run near Fairmount, where it is 2 to 3 feet thick. "It is an extremely ferruginous limestone (iron ore) of brownish-grey color, rather hard, and breaks in blocks of irregular shape."

An analysis by McCreath (3, p. 53) reveals its impure character: $CaCO_3$ 25.089, $MgCO_3$ 6.008, $FeCO_3$ 37.596, Fe_2O_3 1.571, Al_2O_3 4.851, S .083, P .474, Insoluble residue 20.100, Fe 19.250.

Lower Freeport limestone. This limestone which lies from 2 to 8 feet below the Lower Freeport coal is developed locally. Where present it is extremely variable in thickness, ranging from 1 to 6 feet. It has been quarried for agricultural lime but does not make a good lime. It has been found sparingly in Toby, Porter, Red Bank and Piney townships. An analysis (3, pp. 86-87) is given as follows.

$CaCO_3$ 82.000, $MgCO_3$ 6.311, $Al_2O_3+Fe_2O_3$ 2.736, SiO_2 7.940, P. 015.

The specimen analyzed was collected 3 miles northeast from Reimersburg, Toby Township. Exceedingly hard and tough; mottled and stained with ferric oxide; color, generally bluish gray.

It was one time quarried at a point about 4 miles northwest of Shannondale where it is 3 to 4 feet thick but of poor quality.

Upper Freeport limestone. This limestone lies from 3 to 10 feet below the Upper Freeport coal. In most places it seems to be absent. It is from 2 to 5 feet in thickness, dove to gray color, with a fairly well developed conchoidal fracture.

In Perry Township it has been quarried quite extensively. It is about 5 feet thick.

It appears in a few places in Toby Township, especially at Myers Hill, in Porter Township at Squirrel Hill; in Limestone Township 3 miles southwest of Limestone; in Madison Township near Sandy Hollow and New Athens; and thence northwestward more or less continuously to Concord Church in Perry Township.

Analyses of Upper Freeport limestone in Clarion County

	1	2
$CaCO_3$	93.803	82.678
$MgCO_3$	2.270	82.248
$Al_2O_3+Fe_2O_3$	.765	1.365
SiO_2	1.800	5.320
P	.008	.022

1. Freeport Upper limestone. At New Athens, Madison township. Rather fine grained; mottled and seamed with calcite dark gray. (3, pp. 86-87.)
2. Freeport Upper limestone. Reichert's quarry, Perry township. Rather fine grained, mottled with calcite, dark pearl gray. (3, pp. 86-87)

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CLEARFIELD COUNTY

Limestone is not well developed in Clearfield County, although the Johnstown, Lower Freeport, and Upper Freeport limestones have all been recognized. No one of these is continuous or regular in its occurrence, thickness, or physical and chemical characteristics. Half a century ago when limestone was burned locally for agricultural purposes in most of the farming sections of the State where limestones occur, there seem to have been a number of places in the county where one or another of these limestones was quarried in a small way. The writer has failed to obtain any information of any limestone quarrying in recent years and there is no prospect of the county ever having any important limestone operations.

The Johnstown limestone lies 1 to 4 feet below the Upper Kittanning coal bed and is generally from 1½ to 2½ feet in thickness. It is impure and practically worthless, although attempts have been made to use it for agricultural lime.

The Lower Freeport limestone lies 1 to 4 feet below the Lower Freeport coal bed. It is in most cases 2 to 4 feet thick with a maximum thickness of 8 feet. It has been quarried more extensively than any of the other limestones of the county. Its use has been almost, if not exclusively, for burning for agricultural lime for local use. It is normally a gray to dove-colored, compact, crystalline limestone of fairly good quality. The two analyses given on a later page show the chemical composition at two localities.

The Upper Freeport limestone lies 6 to 12 feet below the Upper Freeport coal bed. It is developed in few places in the county and is of little economic importance.

The Vanport limestone is not definitely known to exist in Clearfield County. Since the horizon at which it should be found occurs within the county, it may sometime be found in certain localities.

A few typical occurrences of limestone in the county follow. These are by no means the only localities where limestone is present, but they are representative. A limestone bed near Kylertown, Morris Township, was one time quarried for agricultural lime, but it was found to be too high in iron to burn well.

A hard, compact, bluish-gray limestone, probably the Lower Freeport, was once quarried on the hill overlooking Glen Hope. A sample analyzed by McCreath (3, pp. 77) gave the following results:

$CaCO_3$ 93.810, $MgCO_3$ 1.710, S .053, P .008, Insoluble residue 2.070.

In Jordan Township limestone, probably the Lower Freeport, is said to have been quarried about 2 miles southeast of Ansonville for agricultural lime many years ago.

At Lewisville, Greenwood Township, the Johnstown is said to have been quarried and burned, but with unsatisfactory results on account of its impurities.

The Lower Freeport limestone, 4 to 5 feet in thickness, was once quarried for agricultural lime on several farms a few miles southeast of Pennsville, Penn Township.

In Lawrence Township, about half a mile east of Clearfield, on Clearfield Creek, the Lower Freeport limestone, dark blue and crystalline in character, was once opened. An analysis by McCreath (3, p. 77) gave the following:

$CaCO_3$ 91.880, $MgCO_3$ 1.892, S .135, P .031, Insoluble residue 2.770.

Ashley (5) reports 58 inches of Upper Freeport limestone about 2 miles north of Newtonburg in Bell Township.

In Brady Township, limestone, probably Lower Freeport, has been quarried in a few places northeast and southeast of Luthersburg. "It occupies only the high ground, and is three to four feet thick, gray, compact, sonorous, and when weathered, yellowish or brownish, from the amount of iron, which it sometimes contains. It is burned somewhat for agricultural purposes, but will not make a white lime for plastering." (4, p. 163). South of Troutville a similar limestone is known to be present.

In the southwest corner of Brady Township, along the East Branch of Mahoning Creek, Ashley (5, p. 24) describes a limestone occurrence as follows:

Section of limestone at the W. P. Pifer quarry

	Ft.	*in.*
Soil		
Coal		
Clay	1	
Clay, brownish	3	
Limestone		8
Limestone and clay	1	6
Limestone, dense, compact, bluish gray	2	6
Clay		
Total limestone	4	8

"The correlation of this coal and limestone is not known, but the limestone is about in the general position of the Ames limestone, though it does not have the dark-bluish or greenish-gray color, nor the granular surface due to crinoid stems, that are characteristic of the typical Ames of western Pennsylvania."

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CLINTON COUNTY

The limestones are almost entirely confined to the southeastern part of Clinton County. As in the case of various other sections in Central Pennsylvania, these limestones at one time were quarried in a small way in a number of places, but within recent years there has been little activity except at Salona where two companies have been working for a great many years. One of these, however, has recently closed operations.

The limestones of Clinton County are confined almost exclusively to the Canadian-Ordovician and Helderberg (including the Tonoloway) series, although a few impure limestones have been reported from some of the younger series of rocks.

CANADIAN AND ORDOVICIAN LIMESTONES

The Canadian and Ordovician limestones of Clinton County are found in three anticlinal valleys lying to the south of Bald Eagle Mountain. These are Nittany, Sugar, and Nippenose. Sugar Valley lies entirely within the county whereas only the northeastern portion of Nittany Valley is included, the major portion lying in Centre County. Likewise, only a small part of Nippenose Valley lies within Clinton County, the greater part being within Lycoming County.

Nippenose and Nittany valleys are in a straight line and are part of the same anticlinal fold. The axis itself is wavy and the limestones were brought sufficiently near the surface only in certain portions to permit their solution and the formation of valleys. The uplift was much greater in Nittany Valley than in Nippenose Valley. Only the upper beds of the Canadian strata and the Ordovician strata are exposed in Nippenose and Sugar valleys, but a great thickness of Cambrian beds is exposed in Nittany Valley in Centre County. Erosion has exposed the Canadian and Ordovician limestones in the central portions of all of these valleys. The strata dip away from the axes of the folds and disappear beneath the Ordovician shales that form a continuous band about the valleys. The shales in turn dip toward the sides of the valleys and pass beneath the younger hard resistant sandstones that form the high bounding valley walls. The only easy access to these valleys is along the streams that drain them and that have cut deep narrow gaps in the enclosing barriers.

No railroads enter Nippenose and Sugar valleys. The soil is fertile and some excellent farms are located in them.

Within the Nittany Valley the chief operation is at Salona where the Bellefonte Lime Co. has a large quarry in which there are several grades of stone of commercial importance. At one time lime was burned here but within recent years crushed and pulverized stone alone have been produced. Certain layers only are sufficiently pure for high grade lime whereas a great thickness is suitable for highway construction, railroad ballast, concrete walls and blocks, etc. At one time some of the best stone was pulverized for agricultural use. It was sold under a guarantee of 90.80 per cent $CaCO_3$. The capacity of the crushing plant is 700 tons per day. The quarry face is about 150 feet high and one-fourth mile long. There is a small cave in the west part of the quarry in which the jaw of a Pleistocene bear was

found in 1929. A branch of the New York Central Railroad has been built to the quarry.

J. M. Walker until recently worked a small quarry a short distance to the northeast of the Bellefonte Lime Co.'s quarry to obtain stone for burning. He worked a thickness of about 30 feet of stone, 22 feet of which is a gray, high-grade stone underlain by 8 feet of very dark stone also of good quality. As the two varieties burn differently it is necessary to burn them separately. The lime manufactured was used for spraying, for mortar, and for fertilizing purposes. The average production is about 600 tons of lime per year.

In 1929, a small quarry was in operation for crushed stone 2 miles southwest of Cedar Springs; another one, just south of Parvin; and another similar working about half a mile east of Abdera. In the Parvin quarry a little fluorite was observed associated with vein calcite. In each of these quarries the rock used is fairly high in magnesium. At Cedar Springs, there is an old quarry and two lime kilns. The quarry shows alternate layers of high and low magnesium rocks.

In other places within Nittany Valley old quarries and lime kilns can be found. The so-called Bellefonte ledge of unusually pure limestone is present but is thinner, hence it would not be advisable to open any quarry for this band alone. For stone for crushing there is an almost unlimited amount of satisfactory stone and many favorable sites might be found.

Only the extreme western end of Nippenose Valley extends into Clinton County. Ordovician limestones form the valley floor but no place is known to the writer where the ordinary limestones have been quarried in this part of the valley within recent years.

Platt (3, pp. 80-81) gives the following description of a locality where limestone was formerly quarried and ground for agricultural use.

"In the southwest part of the Nippenose Valley, just across the Lycoming county line and therefore in Clinton county, a so-called plaster is opened on the Joseph Wilsham place.

"The rock dips to the northward 7° or 8°, and in appearance is a bluish limestone, with much calcite, and very fossiliferous in layers.

"This rock has been ground up and used as a plaster, and indeed is now used for that purpose. It sells readily to the county around, in considerable quantities, at prices but little below the Cayuga or Nova Scotia plaster. Mr. Metzgar and others have a mill near the quarry.

"A specimen of the 'plaster' rock and of the ground 'plaster' were forwarded to the Laboratory of the Survey, and on analysis were found to have less than one per cent of soluble sulphate of lime. (A. S. McCreath):

Silicic acid	2.660
Carbonate of lime	95.071
Carbonate of magnesia	1.044
Carbonate of manganese	trace
Phosphate of lime	trace
Carbonate of iron	.261
Sulphate of lime	.744
Organic matter and water	.220
	100.00

"Geologically the horizon of this so-called plaster rock is about 500 feet below the bottom of the slates of III.

"The analysis shows that the rock is in no sense a plaster rock, but simply a limestone."

An interesting deposit in Nippenose Valley belonging to the uppermost part of the Trenton or the base of the Martinsburg (Reedsville) has been utilized as a black pigment or filler. It is an intensely black argillaceous limestone interbedded with black shale that has been quarried by the Penn Keystone Co. about 3 miles west of Rauchtown and, at one time, somewhat nearer Rauchtown. The quarry product is hauled to a mill in the gap south of Antes Fort where it is dried and finely pulverized.

Fossils are rare in the material best suited for the production of black filler but are abundant in the layers of purer limestone, particularly at a quarry once worked near Rauchtown but now abandoned. There the fossils are of Trenton age. The amount of carbonaceous matter present is large and in the weathered portions where the rock has decomposed through the removal of most of the $CaCO_3$, the black coloring matter will rub off readily and resembles lignite in appearance. Pyrite is present in places in the form of tiny crystals, in nodules, and in small veinlets.

Sugar Valley is floored by Canadian and Ordovician limestones which have never been utilized to any large extent. The writer has not had opportunity to investigate the limestones of this valley. The following quotations are taken from Report G4 of the Second Geological Survey of Pennsylvania. (2, p. 36)

"This beautiful and fertile canoe-shaped limestone valley is from one to one mile and three-quarters wide and about seventeen miles long.

"It is surrounded on all sides by the mountains formed by the outcrop of No. IV,—the Oneida and Medina sandstones. Between these and the limestone floor of the valley is a band of slaty and shaly measures (No. III) forming the mountain flank. Very fair land often results from a disintegration of these measures when free from the debris of mountain sandstone with which they are usually covered.

"The anticlinal which elevates the valley-forming limestones of Sugar valley gently dies away at both the eastern and western ends of the valley. The greatest thickness of limestone is therefore brought above water level near the centre of the valley."

"The drainage of Sugar valley is not nearly so irregular as that of Nippenose and Nittany. Sink-holes and underground water courses are more rare. The whole valley is drained by Big Fishing creek which rising at the east end of the valley flows westwardly through its whole length, keeping near the centre of the valley and finally flows into Nittany valley through the sharply cut and tortuous gap at Washington furnace."

Rogers (1, p. 492) gives some additional information as follows: "About three and a half miles from the west end, upon the main road up the valley, a pale blue fetid limestone occurs, speckled with yellow spar like the Nippenose 'marble'. It dips 20°. Sandy limestone in the creek, two miles further east dips 15° north. The anticlinal becomes more regular towards the middle of the valley. In Kleckner's Gap the dip is 30° north.

"The margin of the limestone recedes a little farther from the foot of the mountain east of Kleckner's Gap. At the furnaces there is a quarry of massive strata dipping 10° N.20°E., marking the decline of the anticlinal in that direction."

A small quarry has been worked for road metal recently between Logantown and Carroll.

HELDERBERG AND OTHER LIMESTONES

The Helderberg limestones of Clinton County form a band from one to two miles wide extending entirely across the county, but they are exposed in few places. The Susquehanna River flows through the belt from Lock Haven eastward and Bald Eagle Creek flows through the limestone belt from the Centre County line to its junction with the Susquehanna below Lock Haven. Both of these streams have formed wide flood plains of alluvial deposits that conceal the underlying rock. It is improbable that these limestones will ever be of much value in this section.

Chance (2, p. 46) gives the following statements:

"In the ridge at Farmington (Flemington), between Lock Haven and Mill Hall there are several exposures of a limestone which is probably of Lower Helderberg age, but it is possible that it may be the same with that opposite Lock Haven which belongs either to the Marcellus shale or Upper Helderberg group.

"No measurement of the thickness of these limestones is reliable, as the truth of any calculation based upon the meagre data furnished by these outcrops, is vitiated by the minor folds traversing Bald Eagle valley from Mill Hall to Pine Creek. One of these axes evidently passes through the southern edge of the hill in which the limestone is exposed."

Some other limestones within Clinton County once received some attention, but have long since been almost forgotten. The following descriptions by H. M. Chance furnish more data than can readily be obtained in the field today. (2, p. 55)

"The Marcellus shale is laid bare by roadside cuts and natural escarpments along the river road, just opposite Lock Haven. It here includes a series of impure beds of limestone, which have been tested unsatisfactorily for the manufacture of lime. They were quarried quite largely and used for ballast in the dam, and have also been used for foundation building.

"At first sight it appears as though these beds should be referred to the Corniferous limestone, but they show none of the characteristics of that rock, and are underlaid by black slates, lithologically identical with the Marcellus. Were they Corniferous beds, the Oriskany sandstone should be found beneath them, and in the absence of that stratum they should lie upon the Oriskany lime shales or upon the Lower Helderberg limestones. The interposition of 177 feet of black slaty shales at this horizon, and the absence of a corniferous character, fix their proper position as calcareous bands in the Marcellus.

"They are again exposed along the canal, a short distance east of Lockport, and also about one mile east of town. At the latter locality a slight downthrow fault is beautifully exposed in a vertical cutting on the tow-path."

"At the foot of the mountain (2, p. 45) one mile east of Lock

Haven are two limestone quarries evidently situated on the same bed that has been worked at Mill Hall, and which probably belongs to No. V, occupying the horizon of the Niagara limestone. Both the quarries are opened on the face of the stone, or parallel to the strike, and "strip" rather than "quarry" the rock.

"The following is an average description of the stone exposed:

A.	Massive hard blue limestone	4 feet
B.	Thin bedded, argillaceous, concretionary limestone	5 to 8 feet
C.	Hard massive dark blue limestone, fossiliferous, exposed	6 feet

"Large veins of calcite—sometimes 18 inches thick—traverse the rock along the cleavage planes, and often enclose large water worn sandstone pebbles and more or less triturated fragments of limestone. The presence of these pebbles can only be explained in two ways: 1st, the river may have washed them into the crevices when flowing at a level 40 or 50 feet above its present elevation, or 2d they may have been triturated and worn into pebbles from angular pieces by subterranean water channels in the limestone. The former theory seems more plausible than the latter.

"The dip here ranges from 35° to 45° north by west.

"Baird's quarry which is the most easterly of the two is still working, but the other, which is owned by the city of Lock Haven has been idle for some time. Though the lime yielded by this stone is said to be excellent lime for agricultural purposes, it can not be used advantageously for building, on account of its rather dark color."

"The limestone quarry at the mouth of Fishing Creek gap has been open for many years, but was never very largely worked. About 25 feet of hard, massive, fossiliferous limestone is exposed, dipping nearly vertically to the northwest. It is probably of Niagara age, and has been included in No. V, in the section. The stone has been used for agricultural and building purposes, and also as a flux in the old furnace."

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COLUMBIA COUNTY

The limestones of Columbia County are found at several horizons but with the exception of a very few cases, the only limestones of economic importance are contained in the Helderberg (including Tonoloway) series. Other impure limestones have been found within the county. These are at the top of the Hamilton, where the Tully limestone is developed in places, in the Salina (?), and in the Clinton groups.

The limestones have been utilized mainly for agricultural and building lime. When small iron furnaces using local ores were in existence they were quarried for flux and since the advent of hard surfaced roads and concrete structures, a number have been producing crushed stone. Near the main highways they have been used more extensively. This is well shown by the number of quarries in the band of Helderberg limestones that cross the county from Berwick to Bloomsburg.

HELDERBERG LIMESTONES

The outcrop of Helderberg limestones in Columbia County is in the form of a long loop like a hairpin that extends from the Montour County line eastward to Berwick where the two arms connect. The two bands are approximately parallel to each other and to the course of Susquehanna River between Berwick and Bloomsburg, at which point the river makes a sharp southward bend. The southern band lies close to the river and in a few places is concealed from view by the deep gravel deposits that form the beautiful, almost level terrace. Throughout the county the two bands are 2 to 3 miles apart.

The explanation for the unusually symmetrical occurrence of the Helderberg outcrops is found in the structure. In the folding of the Appalachian Mountains at the close of the Carboniferous, a great anticlinal fold involving these limestones was developed in which the Helderberg lay buried beneath overlying sediments. Erosion since that time has removed the top of this fold, wearing away not only the more recent strata but also the top of the arch of the Helderberg beds and leaving exposed the strata on the sides of the axis of the fold as we find them today.

The Helderberg of the county contains a variety of limestones differing both in chemical composition and physical characteristics. Chemically some beds of massive stone are high in lime and can be used to make a superior grade of lime. These, however, are interbedded with shaly beds, high in silica, alumina, and iron and almost useless where they are thin-bedded, which is commonly the case. Some beds are also relatively high in magnesia. The alternations from massive to thinly laminated beds which is shown in a number of exposures is an objectionable feature.

The Helderberg limestone outcrops in a continuous bluff trending east-west and facing the very flat alluvial terrace extending between Berwick and Bloomsburg. It has been extensively quarried in many places and for a long time. Undoubtedly nearly all the stone was burned for agricultural lime and used for flux for iron furnaces in Bloomsburg and Berwick. In recent years crushed stone has also been prepared.

The beds dip to the south at angles of 30° to 45°. They are in the main fairly regular although in certain places they have been shattered and twisted, producing breccia. Much calcite vein matter is present. Galena, sphalerite, and pyrite are not uncommon in these

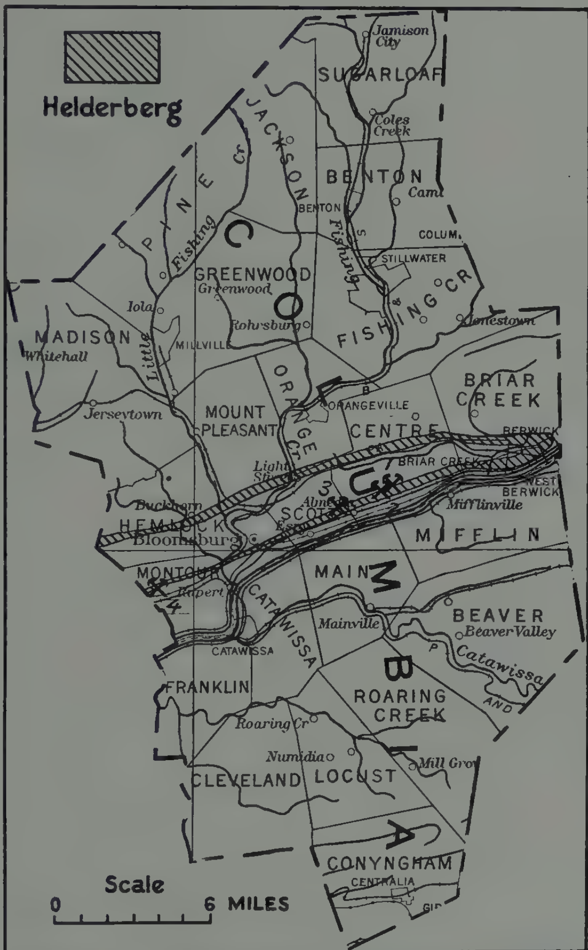

Fig. 10. Limestone areas in Columbia County.

1. Baker Stone Co. 2. Bradley W. Hess. 3. A. M. Hess. 4. E. J. Girton.

calcite veins and north of Almedia the zinc and lead ores were one time mined. White (2, p. 262) describes the occurrence as follows:

"Lead and zinc have been found in small quantity near the western line of this township (Center) in the rocks associated with the bed into which Pohe, Miller, and others have quarried for lime; and some New York capitalists have expended several thousand dollars in attempting to develop the ores in paying quantities. A tunnel for this purpose was driven into the bluff for several rods, just west from where the road turns south to Levi Miller's; but nothing of value was discovered in quantity sufficient to warrant mining, although some rich nuggets of Galena and Zinc ore were found. So far as I could determine, these minerals seem to come in the rocks which be-

long near the junction of the Bossardville limestone with the Upper Salina impure limestones, and are therefore at about the same geological horizon as the lead and zinc mine in Northumberland county, three miles below Sunbury."

Drill prospecting was in progress in 1929 to try to locate a workable quantity of ore. There is an old shaft 150 feet deep. It is reported that altogether $75,000 worth of ore was once shipped from this place. Fine specimens were obtained from the dumps.

The Helderberg in this section contains some excellent stone but also a large amount of shaly material that is worthless. This shaly stone has been thrown into large dumps and now is being hauled away for road construction (not State roads).

The best stone is a dark-colored, rather massive rock that breaks almost like glass. Little "eyes" of white calcite give it the name of "bird's-eye" limestone. This is a very pure calcite stone. Beneath this best layer, there are thin beds of hard limestone with occasional thin beds of shale. This too is used for lime, although it is less pure.

Overlying the good stone is hard impure stone suitable for road metal and some worthless shaly beds. The high-grade stone contains solution cavities in places. The best stone and the thin-bedded limestones are each about 60 to 75 feet thick. The overlying hard, less pure stone and worthless shale probably average 50 feet in thickness.

Inasmuch as the principal workings have been in the south band of the Helderberg limestones, these will be described first.

The Baker Stone Co., a consolidation of the plants of the Paragon Plaster and Supply Co. and Lowe Brothers, located immediately north of Lime Ridge Station and half a mile north of Lime Ridge (Centerville) village has been the most important producer in recent years. The quarry is an old one about one-fourth mile in length and was described by I. C. White in his report (2, p. 260) published in 1883. The section which he gave then is more complete than can be readily made now. It is as follows:

Section in quarry of Baker Stone Co., Lime Ridge Station

		Feet
1.	Limestone, bluish-gray	5
2.	Shaly limestone and limy shales, gray	10
3.	Limestone, bluish-gray, shaly	8
4.	Lime shales	2
5.	Shaly limestone	3
6.	Limestone, blackish, full of *Leperditia alta*	5
7.	Drab, sandy shale *(Stromatopora bed?)*	6
8.	Dark blue limy shale	6
9.	Limestone, bluish-gray and dark	25
10.	Rough, curly limestone, dark blue, fossiliferous	10
11.	Bastard limestone	20
12.	Limestone, blue	20
13.	Bluish-black shelly limestone	40
14.	Limestone, more massive, bluish	6
15.	Limestone, dark blue or blackish	14
16.	Dark blue shelly limestone	15
17.	Shaly, dark limestone to base	10
	Total thickness	205

At present the quarry shows the beds from Nos. 8 to 17. The thicknesses are slightly different than those given above. The No. 8

layer is discarded as waste, Nos. 9 to 11, consisting of hard stone, are crushed for road metal, and Nos. 12 to 17 burned for lime. The thickness of good stone for lime is slightly over 100 feet. The upper portion, 60 to 70 feet, is mainly a dense blue stone, breaking with a glassy fracture and containing numerous eyes of white calcite. The underlying material is thin-bedded and contains some shaly bands.

There are 11 stone kilns on the property, 9 of which were in operation in 1929. Part of the lime is hydrated. The company has announced its intentions of pulverizing some of the raw limestone for fertilizing purposes.

West of the Baker quarry, Bradley W. Hess works a small quarry and burns lime. He has 3 kilns.

Much quarrying has been done in the ridge just north of Almedia and there are very large quarries there. In 1929 only one was in operation and that on a small scale. A. M. Hess was working an old quarry for just enough stone to supply one kiln and burning lime for agricultural use. The quarry follows the strike about 1200 feet and the working face is about 150 feet high. The beds dip southward at an angle of about 35°. In this opening the beds were quarried below the road level, not common in this section, and a big opening is now filled with water.

Dr. Frank Baker also owns a large quarry in the same area which was idle in 1929. It was in this quarry that much galena and sphalerite were once obtained although the principal mining for these materials was done a short distance to the west.

In the southern Helderberg band west from Bloomsburg in Montour Township, only one quarry was in operation in 1929, although several were being worked in this band just across the county line in Montour County. The quarry in operation was that of E. J. Girton, about 2 miles west of Fishing Creek on the north side of the highway. This is the old Eck quarry described below. There are 3 kilns but only 2 in use. The plant is in operation in the spring and fall to supply lime for the farms of the vicinity. The stone quarried is a thin-bedded black limestone. Since this section was once the site of extensive quarrying and the operations have been quite fully described by I. C. White, it seems advisable to quote from him.

"The lower Helderberg limestone (2, p. 244-249) makes a low ridge through the township bounding the northern side of the Hamilton valley and separating it from the Salina valley next north. It is quarried at several places in the township, and we shall now describe the principal of these, beginning at the west and going eastward.

"The first quarry is about one half mile east from the western boundary and is known as the Mauser quarry. At that locality the following section revealed at the numerous excavations and cuttings made in quarrying:

Mauser's Quarry

		Feet
1.	Soil	5
2.	Limestone, shaly and flaggy, bluish	10
3.	*Stromatopora* bed, a massive, bluish-gray limestone, composed almost entirely of *Stromatopora concentrica*	12
4.	Limestone, shaly, bluish	5
5.	Limestone, massive, gray, containing vast quantities of *Halysites catenulata* (Niagara)	20

6. Limestone, rough, gray, somewhat crystalline, a mere mass of Crinoidal fragments, broken shells, and a coral very much resembling *Cladopora multipora*		12
7. "Bastard limestone," a buffish impure magnesian bed, containing *Beyrichias*, *Strophomena rugosa*, *Atrypa reticularis*, and very probably representing the Stormville Cement beds of Pike and Monroe counties		20
8. Bossardville limestone:		
a. Dark blue or blackish limestone in thin, flaggy layers, much streaked with calcite; the purest bed in the series, known to the quarrymen as the "main branch"	35	
b. Shaly limestone, dark-blue, the layers only ¼" to 1' thick, impure	35	
c. Flaggy limestone, dark blue, quite good	30	
d. Shaly limestone, bluish-gray to bottom of exposure	10	
		110
Total thickness of limestone measured		189

"No. 2. A line of cherty sandstone bowlders 20 to 25 feet above the top of No. 2, marks the presence of the Stormville conglomerate horizon of Pike and Monroe.

"A well just below the base of the Bossardville beds brought up the impure buffish and pale green beds of the Salina.

"Therefore if we add 25' to the top of the section and 10' to its base we should have about 224' for the entire thickness of the Lower Helderberg limestone at this locality exclusive of the Stormville shales; including these would raise the thickness to 300'.

"No. 3. The *Stromatapora* bed is certainly identical with the stratum noted in the Stormville limestones of Pike and Monroe which contained so many *Stromatoporae;* and its occurrence here gives an unmistakable and valuable horizon for correlating the beds of the Monroe county Lower Helderberg with that of Columbia and Montour. This stratum is one great reef of *Stromatopora concentrica* which stands out from the weathered cliff in masses 2"-18" in diameter.

"No. 5 is much the most interesting bed of the series, for in it I found *Halysites catenulata* covering the surfaces with its beautiful chain-like tubes, and forming in some portions of the bed quite as large a part of the rock as the *Stromatopora* does in No. 3. The occurrence of *Halysites catenulata* in the undoubted Lower Helderberg here, is most interesting, from the fact that it has always been regarded as perfectly characteristic of the Niagara period; but here we find it surviving to near the close of the Lower Helderberg period, which overlies more than 1000' of Salina beds.

"Both Nos. 3 and 5 are quarried and burned by Mr. Mauser, making good strong lime for agricultural purposes, but not sufficiently white for plastering.

"No. 7 is called the "bastard limestone" by the quarrymen, from the fact that it is too impure to be used for burning, and hence is always rejected. It is of a buffish tint, generally, but occasionally an ashen gray, sparingly fossiliferous, quite tough and used sometimes for building stone. This bed is persistent for nearly 20 miles across Columbia county; and since it is somewhat magnesian and comes at the same horizon as the Stormville cement bed of Pike and Monroe, I have identified it with the latter, although the Decker's Ferry sandstone and shales come at the same horizon.

"No. 8. The Bossardville limestone of Pike and Monroe is perfectly represented by No. 8 (a, b, c, d) in structure, in lithology, and in every other respect. There can be no doubt whatever of the correctness of the identification, for the Salina buff and pale green limy shales come immediately below No. 8, as the same Salina (Poxono) beds do in Monroe.

"(a). The upper division of the Bossardville limestone is the purest portion of the whole Lower Helderberg limestone, and is usually quarried out entirely before any of the other beds are touched. It makes an excellent lime for plastering, and all building purposes, and is in high repute as a fertilizer.

"The rocks pitch S. 10°E.30°-40° at this quarry.

"Appleman's quarry. Just east from Mauser's the Main Bench (8a) of the Bossardville limestone has been extensively quarried by Mr. S. Appleman who has confined his operations entirely to that bed, and mined it to a depth of 30′ for more than one fourth mile along the strike; the heavy bed of "bastard limestone" preventing access to the Stormville limestone above it without expensive cuttings through the former since the rocks pitch southward at an angle of 40°.

"A bed of cherty sandstone 4′-5′ thick and containing *Spirifera arenosa* is seen in descending Appleman's run from his quarry to the Danville road. It comes directly beneath the dark Stormville shale and is very probably identical with the Stormville conglomerate of Monroe Co.

"Eck's quarry is about one half mile east of Appleman's.

Charles Eck quarry

		Feet
1.	Soil	2-5
2.	Limestone, bluish-gray	8
3.	*Stromatopora* bed	10
4.	Limestone, bluish-gray, very fossiliferous, containing *Favosites, Zaphrentis, Stromatopora, Crinoidal* fragments and other fossils	20
5.	Limestone, slaty, dip S.15°E.38°	5
6.	Bastard limestone	15
7.	Dark, blue, flaggy limestone, "main bench," best in quarry	20
8.	Bluish-gray, shaly, flaggy limestone, full of *Leperditia alta* for 10′-15′ at top, layers only ½″-1″ thick	30
9.	Bluish-black limestone, more massive	15
10.	Shelly limestone	5
11.	Limestone, bluish-gray	1½
12.	Shelly limestone, bluish-gray to base of exposure	2

"No. 3. The *Stromatopora* bed is here, as at Mauser's, a mass of *Stromatoporae* and other corals, many of which are beautifully weathered out of the matrix.

"No. 4 is also very fossiliferous at this locality, though the *Stromatoporae* are much less abundant than in No. 2 *Crinoidal* fragments and a species of *Cladopora,* a delicate branching form, seem to be the most numerous. *Atrypa re(c)ticularis* also occurs here. Both Nos. 2 and 4 have been quarried and burned at this locality, but No. 7, the top of the Bossardville series, is the one mostly quarried since it furnishes the purest lime.

"No. 6. The "bastard limestone," has its usual buffish-gray tint, and is full of minute fossils which are probably *Beyrichias.*

"The Bossardville beds are represented by Nos. 7-12, which do not, however, include all of that series, since 30'-40' are concealed below the base of No. 12, the lowest layer exposed.

"No. 8 is filled with *Leperditia alta* in its upper half; they cover the thinly laminated layers by the thousand.

"The top of the Lower Helderberg limestone at Eck's quarry comes up to the surface on a rapid (40°) south dip at 200 yards north from the Bloomsburg and Danville road.

"The next quarry in the Lower Helderberg limestone is about ¼ mile east from school-house No. 1, on the land of Mr. J. S. Mensch, and is one of the oldest in the county, having been operated for a period of more than 60 years.

"The following section is exposed:

J. S. Mensch's quarry

		Feet
1.	Soil and yellow loam	10-15
2.	Limestone, bluish-gray, full of Crinoidal fragments and other fossils	6
3.	Shaly, gray limestone	5
4.	Bastard limestone	30
5.	Bossardville limestone, bluish-black, thin layers of very good limestone veined with much calcite ... visible	25

"Nos. 2 and 3 have been quarried to a small extent, but No. 5 furnishes the principal quarry rock. In the bastard limestone which has an unusual thickness here were seen *Atrypa recticularis, Beyrichia,* sp.?, *Strophomena depressa,* and *Rhynchonella formosa.*

"The top of the Bossardville limestone, No. 5, has been quarried out along the hills in both directions (east and west) under the massive bastard limestone which overhangs the excavations, dipping southward at an angle of 35°-40°.

"Evan's quarry. East of Mensch's the Helderberg limestones are covered up until we come to Big Fishing creek, just east from where the Bloomsburg road first strikes its banks, and turns north near I. M. Evans'. Here this limestone comes out from under a great bed of coarse, reddish sand, and extends in a solid wall 5′-6′ high, nearly across the creek. The limestone has been quarried here along the stream, by Mr. Evans, where about 50′ of the rock are exposed, seemingly the lower portion."

The north band of the Helderberg east of Fishing Creek lies almost entirely in the valleys of East Branch and West Branch of Briar Creek. A number of quarries have been opened in this band but most have been small. Beginning about one mile northwest of Berwick, there are four old workings in the north side of the ridge that lies south of the East Branch of Briar Creek. One of these was worked only a few years ago to get stone for agricultural lime. In no one of these quarries did the stone appear desirable because of the large amount of thin-bedded, more or less shaly stone. There are some layers of good stone, but the horizon so largely worked on the southern band does not seem to have been opened. The beds dip on an average about 25°N. White (2, pp. 263-264) describes several quarries near the western part of Center Township in most of which the stone is "very dark blue, almost black, in thin, flaggy, layers through which radiate streaks of calcite." The stone was burned for lime. Part of the lime was of inferior quality.

A small, long-abandoned quarry was observed about half a mile southwest of Whitmire. The beds are thin and dip north.

The north band of the Helderberg limestones has been little worked west of Fishing Creek. It passes through the north part of the little settlement of Buckhorn and was once quarried about two-thirds mile east of the village to obtain stone for agricultural use in the neighborhood.

OTHER DEVONIAN AND SILURIAN LIMESTONES

Salina (?) limestones. Beneath the beds of the Helderberg that have been worked throughout Columbia County, there is a thickness of 736 feet, as determined by White, in which a number of limestone layers alternate with green and buff shales that he refers to the upper and middle members of the Salina group. It is believed that at least part of these should be placed in the Tonoloway but careful stratigraphic and paleontologic studies must precede a definite decision. White gives the following section (2, pp. 103-104) along the road connecting Bloomsburg and Light Street Village, beginning about 2½ miles above Bloomsburg:

Section along Big Fishing Creek

	Feet
Upper Salina group	
1. Pale buff and greenish magnesian limestone, quite impure	75
2. Shales, limy, pale green	10
3. Limestone, impure, pale green	10
4. Concealed	5
5. Limestone, and limy shales	10
6. Concealed	8
7. Buffish shaly limestone	15
8. Pale green, magnesian limestone	15
9. Bluish gray limestone, impure	5
10. Buffish, limy shales	10
11. Blue, shaly limestone	10
12. Buff and greenish shales	18
13. Bluish gray, impure limestone	4
14. Pale green, limy shales	15
15. Bluish gray limestone, rather pure	2
16. Buffish, limy shales	2
17. Pale green, shaly limestone, and limy shales	55
18. Buffish, magnesian limestone	15
19. Blue, shaly limestone	5
20. Greenish, limy shales	40
	329
Middle Salina group	
21. Pale green, limy shale with purplish cast	7
22. Red shale, containing 10-12 per cent of iron	5
23. Shales, limy, pale green	30
24. Buff, and bluish, magnesian limestone	5
25. Pale green, limy shales	25
26. Concealed	15
27. Bluish, limy shales	10
28. Greenish, limy shales	35
29. Red shale	5
30. Concealed	5
31. Greenish gray, sandy shales	15
32. Pale green shales	30
33. Concealed	40
34. Green shales	10
35. Red shale	5
36. Concealed	5
37. Green shale	5
38. Red shale	5
39. Variegated shale (red and green)	5
40. Limestone, bluish gray, good	3
41. Green shale	10
42. Red shale	10
43. Green shale	20
44. Limy shale	5
45. Limestone, gray, rather pure	4
46. Green shale	3
47. Red shale	20
48. Limestone, gray, impure	5
49. Concealed	5
50. Green shale	5
51. Concealed	20
52. Red shale	5
53. Greenish shales, containing thin, bluish gray, impure limestones	20
54. Green shale	10
	407

So far as known these limestones have not been utilized in Columbia County and they have little possible economic use.

Clinton limestones. In this part of the State the Clinton is well developed and contains some fossil hematite ore that was once mined in several places. The fresh hard ore contains considerable $CaCO_3$ normally and is believed to be the replacement of calcareous fragmental shells of organisms. In places the replacement has been only partial and we find a ferruginous limestone. White (2, p. 234) states that in Hemlock Township "a bed of limestone, 6 feet thick was once mined in the Clinton upper shales, on the land of Mr. Evans just east from Wedgetown. It comes about 50 feet above the fossil ore, is dark blue, and not very pure. Some fragments of fossils were seen in it."

Tully limestone. Just above the Hamilton shales there is a series of calcareous beds that have been termed the Tully limestone. They are from 40 to 50 feet in thickness and have been observed in Madison, Mount Pleasant, Hemlock, Mifflin, Maine and Catawissa townships. White (2, pp. 76-77) describes this series of beds as follows:

"This limestone is never pure enough to burn, being usually quite earthy, breaking with a dull, irregular fracture, and often weathering to a light ashen, or even buffish gray color. It is exposed at many localities in the district, but the best places for seeing it are in the cuts of the North Branch R. R., between Mifflinsville and a point opposite Bloomsburg. The fossils given from it in the section above were obtained in a cutting along the North Branch R. R. at the south side of the ferry opposite Bloomsburg. The same fossils occur in this limestone, however, on Little Fishing creek and elsewhere in the district."

Onondaga limestone. The Onondaga limestone is rarely seen in the county and is of no economic importance. It consists of gray, non-cherty limestone with interbedded, gray, calcareous shale.

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CRAWFORD COUNTY

Although limestone occurs at three different horizons in the geological section of Crawford County, at no place are there any deposits of more than local importance. Each of the limestones described is thin, normally from 1 to 2 feet in thickness, and in addition all are fairly high in silica. Some were burned for lime many years ago but local lime burning on a small scale is a custom that has now practically been abandoned. Some of the ledges where stone could be easily obtained might yield some satisfactory stone for structural purposes. However, there has been little or no quarrying of the limestones of the county for this use on account of the large supply of high-grade structural sandstone. The calcareous marls which have never been adequately investigated are beyond question of greater economic importance than any of the limestones.

Geological section of Crawford County

- Pennsylvanian
    - Pottsville series
        - Homewood sandstone
        - Mercer group
        - Connoquenessing group
            - Upper Connoquenessing sandstone
            - Quakertown shales
            - Lower Connoquenessing sandstone
        - Sharon group
            - Sharon iron shales
            - Sharon coal
            - Sharon conglomerate
- Mississippian
    - Pocono series
        - Burgoon group
            - Shenango shale
            - Shenango sandstone
        - Cuyahoga group
            - Upper Meadville shale
            - *Upper Meadville limestone*
            - Lower Meadville shale
            - Upper Sharpsville sandstone
            - *Lower Meadville limestone*
            - Lower Sharpsville sandstone
            - Sunbury (Orangeville) shale
        - Berea (Corry) sandstone
- Devonian
    - Upper Devonian series
        - Catskill-Venango group
            - *Venango (Cussewago) limestone*
            - Shales and sandstones (440 feet)
        - Chemung group
            - Shales and sandstones (325 feet)

VENANGO LIMESTONE

The Venango (Cussewago) limestone has been recognized in the northwestern part of Crawford County. Having a southerly dip, it disappears below the valleys of the streams in the southern part of the county. It has been named from Cussewago Creek along which it outcrops. It is also exposed in many places along French Creek and its tributaries above Meadville and along Conneaut Creek and other small streams in Beaver, Spring, and Summer Hill townships.

In thickness the Venango ranges from 1 to 2 feet. It is a hard limestone, high in silica, and breaks with a glassy fracture. It appears to be unfossiliferous.

Near Littles Corners it is well exposed in several places. It is about 1½ feet thick here. White (3, p. 220) describes an occurrence about 1 mile west of Venango as follows: "The Cussewago limestone is here an unusually massive layer of hard rock, huge blocks of which 6′ to 8′ square, and 2′ thick, lie along the little stream, as they have been torn from its bed. Possessing more lime than usual in its composition, it has been burned with some success by Mr. Norris, into good white lime. The rock is very compact and breaks with a sharp, angular fracture, and the characteristic glistening surface."

MEADVILLE LIMESTONES

Lower Meadville limestone. Due to the slight importance of the Meadville limestones and lack of time, they were not investigated by the author. The descriptions of I. C. White (3, pp. 87-89) are therefore quoted with slight changes or else furnish the basis for the accounts that follow.

"This thin bed of impure limestone lying 235 feet above the level of the level of the canal at Meadville is as remarkable a geological horizon as the Meadville Upper limestone.

"Wedged in between the Sharpsville Upper and Lower sandstones, weathering like them, and covered by their fragments I saw nothing of it at first in my survey of Mercer County.

"Seldom more than 2 feet thick, and often only 1 foot, it is nevertheless so persistent, that I found it in every part of Crawford county; afterwards in Mercer county, along the Shenango valley for 21 miles, to where near Sharon it goes beneath water level; on the Allegheny river, rising from water level between Franklin and Oil City; cropping out all along the west bank of Oil creek at 1173 feet A. T.; and at Tidioute 375 feet above the Allegheny river bed; and represented, perhaps, by fragments on the Brokenstraw, at Garland, 135 feet beneath the Shenango sandstone.

"From the base of the Sharon Conglomerate down to the Meadville Lower limestone, I make the interval, in Crawford county, never less than 190 feet.

"This limestone is very hard and flinty, breaking with the same peculiar fracture mentioned already in the description of the Meadville Upper limestone. "It lies,' says J. T. Hodge, who first described it, 'in large and nearly square masses, the angles of which are more or less rounded off, showing the readiness with which the lime is dissolved out of the rock. By the removal of this ingredient, and the

oxidation of the iron in the stratum, it acquires a brown siliceous crust, sometimes thick, indicating it is to be feared too large a proportion of sandy matter, to qualify this rock to be converted even into an impure lime. In an attempt once made, the excess of sand in the rock produced with the lime a slag.' (In Prof. H. D. Roger's Third Annual Report to the Legislature, 1838, p. 111, 112. Restated in Geology of Pennsylvania, 1858, vol. I, p. 584.) This feature characterizes also the Cussewago limestone.

"The hardness of these limestone beds compared with that of the measures enclosing them cause little water-falls in the beds of the streamlets, descending the hill slopes; and in some places the water flows over the limestone stratum for a considerable distance above such a cascade.

"Non-fossiliferous, in Crawford county, as a rule, this Lower Meadville limestone, differs in a striking manner from the Upper one. At one or two localities only I found a few fish scales and Linguloid shells.

"A very good and nearly pure white lime has been made from this stone in certain exceptional localities in Crawford county. On Deckard's run it was once quarried to a considerable extent by Mr. Shuey and burned into plastering lime. As flux for Liberty Furnace, mixed with Lower Mercer limestone from near Utica it was a failure.

"Analysis, by Dr. F. A. Genth, of a more than ordinarily siliceous specimen:

Carbonate of iron	3.62
Carbonate of manganese	0.31
Carbonate of magnesium	1.70
Carbonate of calcium	27.61
Alumina	4.24
Silica	60.43
Water	1.74
Total	99.65

"Judging from the appearance of the specimens the silica is usually not more than 20 per cent of the whole.

"Outcrops excellent for study may be found in Crawford county, near Jamestown, in the hollow down from the bridge below Snodgrass's quarry; near Meadville, in the cemetery grounds, at the hydraulic ram on Mill run; at Geneva, Greenwood Township, bed of run just west of R. R. station; in Hayfield township, west branch of Cussewago creek, heads of ravines."

Upper Meadville limestone. White has described exposures of the Upper Meadville limestone in most of the townships in the southern half of Crawford County. In most places it is approximately 2 feet thick although in some localities it is only 1 to 1½ feet. Wherever noted, it is extremely fossiliferous and the remains of fishes are most conspicuous. "Fish scales, (3, p. 83) teeth, bones, plates, and spines are so crowded in it that at many localities it might be called a fish bone conglomerate, in which it is difficult to detect any other materials." It does, however, contain many brachiopods, mollusca, and other forms.

"Rounded pebbles (3, p. 84-85) of shale and fine sandstone are nearly always to be found in it; usually of a dark color, and derived

from some older strata of the series. In some places these pebbles are immensely numerous. They are usually flat or lenticular, sometimes worn oval, and tapering to a blunt point.

"The limestone matrix is not a pure carbonate of lime; but contains much silica, etc., and often resembles a sandstone weathered. The rock has the peculiar sub-carboniferous-limestone fracture of this region, the broken surface being covered with many small elliptical, glassy, sparkling spots (which look like small shells until they are closely examined) due to a semi-crystallization of the carbonate of lime.

"The best places to study this rock and to collect its fossils are as follows:

"The gorge south of Glendale (Custards); the ravines east of Meadville leading into Mill run; the ravines 2½ miles east of Meadville descending to Woodcock creek; Grassy run, in Wayne township, a very fine locality; the ravine at Jamestown; and at McElhenny's 2 miles north of Jamestown.

"Good exposures can be found on the numerous small streams descending to Adamsville; but fish remains can be found almost anywhere on all the lines of out-crop."

The Upper Meadville is everywhere fairly high in silica so that it has not been used much for lime. Nevertheless, it has been utilized to a limited extent. It was once mined and quarried about half a mile above Deckards where it is 2 feet thick. It is quite siliceous so when used at an iron furnace (Liberty) it was mixed with Lower Mercer limestone from Utica, Venango County. It was also burned for lime at this place and is said to have yielded an "exceedingly white lime." (3, p. 125). It was also once quarried along a small tributary of Lake Creek and burned for lime. It made a "very fine white lime though it had to be calcined quite long before it would slack well."

White has given brief descriptions of this limestone in Wayne, East Fairfield, Union, Greenwood, Vernon, Mead, Richmond, East Fallowfield and South Shenango townships.

CALCAREOUS MARL

The best known deposit of calcareous marl in the State is located in and near Conneaut Lake in Crawford County. This has been worked at different times. The following descriptions are from reports of the Second Geological Survey of Pennsylvania (2, pp. 363-365).

"The only specimens of marl thus far examined are from the deposit at Harmonsburg. It occurs in Summit township, Crawford county, on the adjoining farms of Almon Whiting and Benjamin Brown. The bed is estimated to contain eighty acres. It lies about one mile N.N.E. of the north end of Conneaut lake, on a little stream emptying into the lake at Gregher's mill, and at an elevation above the present lake surface of say twenty feet. It is a lenticular deposit, thin at the edge, and thick at the center, occupying the principal part of a small swamp or basin between low hills of drift. A stratum of peat, about two feet thick, overlies the marl and supports the swamp vegetation covering the surface.

"Pits have been sunk where the marl is fifteen feet thick, and a boring near the center of the deposit was carried down twenty-two

feet without reaching its base. The bed, therefore, may be said to be from three feet to twenty-two feet in thickness.

"Geologically speaking, the deposit is of recent date. It lies within the walls of an old river valley, now holding more than three hundred feet of northern drift, brought down by the ice of the Glacial epoch, and cannot, therefore, be as old as the drift. It probably accumulated when the waters of the Conneaut lake stood at a higher level than at present; or this swamp may have been an independent lakelet which has since been drained by the gradual lowering of its outlet leading into Conneaut lake. The indications are that it was a deposit made in shallow water, for a precisely similar bed (except as to the peat, which no doubt has accumulated since the lakelet was drained) is now found at the bottom of Cassadaga Lake, Chautauqua County, New York, covered by from ten feet to thirty feet of water. Large quantities of the material have been raised by dredging, and prepared for use. The Cassadaga marl is more compact than the Harmonsburg marl in consequence of not being so thickly pierced by the long, vertical rootlets so noticeable in the latter; but the two deposits are evidently of the same character and belong to the same age.

"Ever since 1830, occasional crude attempts have been made to dig this Harmonsburg marl, and convert it into lime for mechanical and agricultural purposes. The mortar used in several brick buildings in Meadville, built more than thirty years ago, was made from lime manufactured here, and it is said to stand the test of time well.

"But no successful attempt to permanently utilize the marl seems to have been made until about the year 1874, when Mr. Almon Whiting erected a dry-house and stone lime kiln, and secured a steam engine and pumps for relieving the pits from water while cutting the material. Since that time quite a business has been established, both in the manufacture of lime and fertilizers.

"The peat is first stripped off, and then the marl is cut out in brick-shaped blocks, and corded up to dry. This work is usually done in the month of June, and in August it will be sufficiently dry to be burnt. The process of burning occupies three days and nights. In dry weather, this is done by piling up in the open air alternate layers of wood and marl as high as convenient, but when the weather is wet, the burning is carried on in a kiln in the usual way. The product is then run through a mill and ground so fine that it can be applied to the land by means of the common grain drills, with proper attachments.

"A considerable quantity of this marl has already been used for agricultural purposes, and where the soil is dry and in a suitable condition the results have proved very beneficial."

"Under the peat at Mr. Whiting's (3, pp. 40-42) comes a great bed of fresh-water shell marl, formed from the partial decay of fluviatile shells, principally univalve. The marl is mined to a depth of 6 to 8 feet, and Mr. Whiting bored down through the deposit to a depth of 22 feet, and still did not pierce its bottom.

"The peat bog in which this marl occurs, has now an elevation of 25 feet above the present level of Conneaut lake, as near as I could determine it by barometer, and there can be no doubt that this lake, now 1½ miles distant, once spread its waters over the marl beds, since there are about 60 acres of the marl on the land of Mr. Whiting, and

a large amount on the land of Mr. Brown, adjoining, where, according to report, a bed of peat was found beneath the marl.

"A collection of the more common shells found in the marl deposit was made and forwarded to Mr. George W. Tryon, Jr., of the Phila. Academy of Science, who kindly identified them and sent the subjoined statement:

" 'The fluviatile shells from the vicinity of Conneaut lake are all representatives of existing species, which ought to be found in the lake and are found throughout the waters of the State. I do not find any of the extinct forms which are so abundant at White Pond, Warren Co., N. J., a locality which, so far, has furnished several species peculiar to it. The following are the names of the species:'

Planorbis bicarinatus, Say.
Planorbis trivolvis, Say.
Planorbis campanulatus, Say.
Planorbis parvus, Say.
Physa heterostropha, Say.
Limnaea humilis, Say.
Amnicola limosa, Say.
Sphoerinum striatinum, Lam.

"The mode of accumulation of the marl beds is evident. There are found running through the marl from the top as far down as it has been explored (and presumably to the bottom) the stems of the ordinary Pond-weed, or a species very closely allied to it. These water plants grew and flourished in the old lake bottom, and on them countless millions of river molluscs fed and found a home just as we now see them in the shallower parts of the lake where the water grass grows. Their cast-off shells, etc. accumulated and were ground together by the waves into a bed of marl.

"As the water grass or pond weed will not grow in water of a greater depth than five or six feet—I have myself seen none growing in water deeper than four feet—and as the bed of marl is at least twenty-two feet thick, the level of the lake water surface must have gradually risen during the formation of the marl; and at the same rate; so as to allow the grass always to be growing in a proper depth of water.

"This marl is a good lime manure, and that is all; for the phosphoric acid and alkalies are in very small quantities.

"Marl beds are reported to exist in the Conneaut lake creek marsh; and this makes the former extension of Conneaut lake in that direction certain."

An analysis made by the U. S. Department of Agriculture is as follows:

Marl analysis

	Per cent
Water and organic matter	4.00
$CaCO_3$	71.14
$CaSO_4 + MgSO_4$	3.25
Silica SiO_2 (traces of alkali salts)	21.61

Analyses of Crawford County marl

A. S. McCreath, analyst (2, p. 365)

	1	2	3	4
SiO_2	1.052	7.940	10.978	11.541
Al_2O_3	.020	.810	1.119	.808
Fe_2O_3	.170	850	1.176	.860
FeS_2	.429	.000		.071
CaO	49.129	59.800	82.679	44.997
MgO	.839	1.405	1.943	1.163
$K_2O + Na_2O$	.116	.322	.445	.538
SO_3	.222	.841	1.162	.877
P_2O_5	.023	.042	.058	.062
CO_2	39.356	13.590		33.890
Organic matter	6.510	1.010		3.900
H_2O	2.190	12.950		1.340
Total	100.056	99.560	99.560	100.047

1. Raw marl, Harmonsburg.
2. Mixed masses of marl taken from different pits and at varying depths, and burned in close kiln to a white heat.
3. Same specimen when thoroughly and freshly burned.
4. Marl burned in open air to a red heat.

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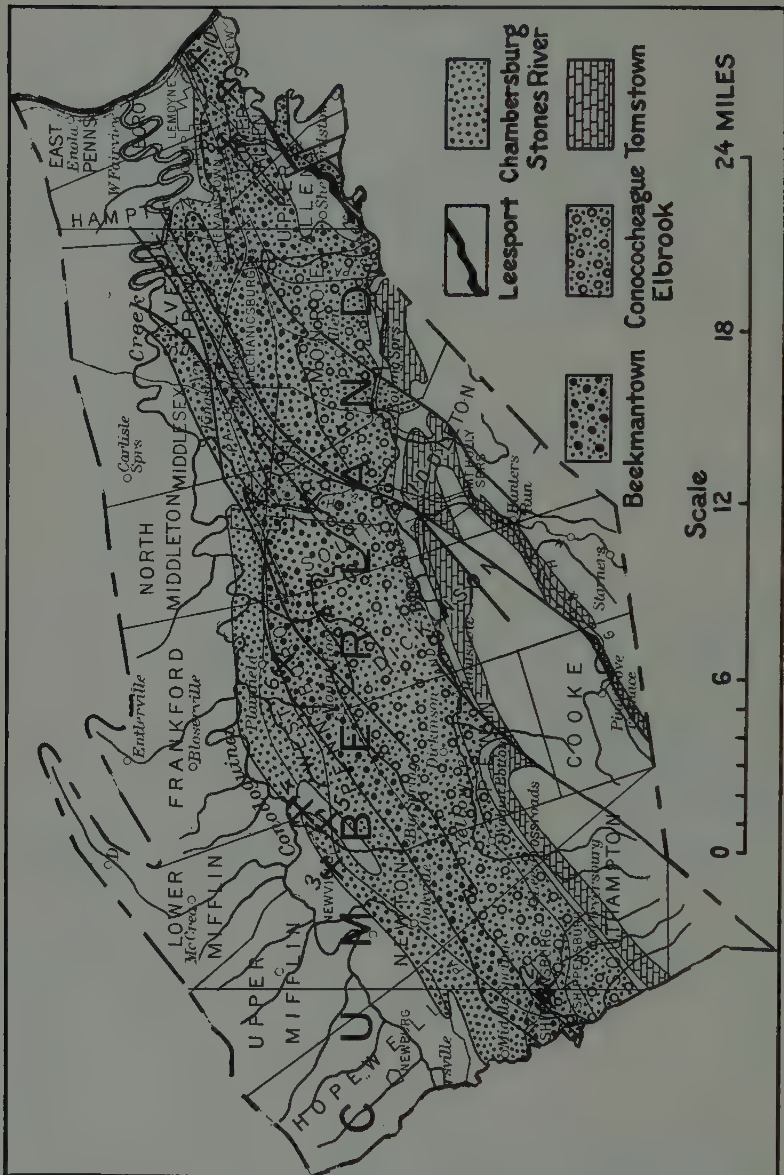

Fig. 11. Limestone areas in Cumberland County.

1. Shippensburg quarry
2. Huber Coy
3. Spangler Pulverizing Lime and Stone Co.
4. D. H. Heller
5. Vincent Hamilton
6. Joseph Erford
7. Bonny Brook quarry, J. F. Sours
8. Bushey quarry
9. Hempt Brothers
10. Lemoyne Quarries (Walton quarry)

Cumberland County is well provided with limestones as they outcrop in a band extending entirely across the county, occupying almost one-third of the total area. This band, which forms the Great Valley, is almost in the center of the county from north to south and includes almost all the towns of importance.

Notwithstanding the extensive area of limestones, much less quarrying has been done in Cumberland County than in a number of other counties less well supplied. This is primarily due to the fact that there are no large towns and few large industrial plants requiring limestones or limestone products. The variety of limestones present and the many locations favorable for quarrying give promise for the future, when it may become profitable to exploit them.

Apparently there has never been a time when there was any large amount of quarrying done. More quarries were in operation in the days when many of the farmers produced their own lime for farm use or supplied some of their immediate neighbors. This situation has now largely passed away.

More than one hundred old iron mines have been worked in Cumberland County and most, if not all, of the iron ore was smelted in local furnaces with local limestones for flux. With no iron mines or iron furnaces in operation for many years past, there has been practically no demand for fluxing stone.

Building stone has been quarried on a small scale for local use, but has never been important. In recent years fewer stone houses have been erected than at an earlier day.

The construction of permanent hard roads and concrete structures has been the principal mainstay of the quarrying industry of the county in recent years and the great bulk of the limestone now being quarried is sold as crushed stone. For this purpose almost all of the limestones of the entire region are serviceable.

Whenever it becomes economically practicable to erect a cement plant in the Great Valley west of Susquehanna River, the limestones of Cumberland County should receive careful attention as it is fairly certain that there are locations there where suitable stone can be readily obtained.

The limestones of Cumberland County belong to the Cambrian and Ordovician systems and are similar to those found in Franklin County to the southwest and in Dauphin and Lebanon counties to the east.

*Geological table of limestone formations in Cumberland County**

	Approximate thickness in feet
Ordovician	
Martinsburg shale series	
Chambersburg limestone group	100-750
Canadian	
Stones River limestone group	675-1050
Beekmantown limestone series	2300
Conococheague limestone group	1500
Cambrian	
Elbrook group	?
Waynesboro group	?
Tomstown group	1000
Sandstone and quartzites	

* This table has been arranged to follow the official section of the Pennsylvania Geological Survey although the author prefers the U. S. Geological Survey section hich does not include the Canadian system.

This table and the brief descriptions which follow are largely compiled from the Mercersburg-Chambersburg Folio (No. 170) of the U. S. Geological Survey by George W. Stose.

CAMBRO-ORDOVICIAN LIMESTONES

Tomstown limestone. The Tomstown limestones, the lowest limestones in the county, mainly confined to the southern part of the Valley close to South Mountain, are of lesser importance than some of the higher lying limestones. They consist of dolomitic limestones with varying amounts of magnesia and silica, although both are relatively high. There is considerable shaly interbedded material in most places.

Conococheague limestone. Overlying the Tomstown limestones, there have been recognized in parts of Cumberland County some sandstones and shales with minor amounts of dolomitic limestones referred by Stose to the Waynesboro and Elbrook formations. Above these come the Conococheague limestones consisting of thin to moderately thick beds of dolomitic limestones with occasional thin shale partings. Limestone conglomerate, edgewise conglomerate, oolite, mud-cracked and ripple-marked surfaces and fossil algae called *Cryptozoon proliferum* are all common features of these limestones.

Beekmantown limestone. The Beekmantown strata directly overlie the Conococheague limestones. They consist mainly of low-magnesian limestones, although in places there are interbedded dolomites. On fresh fractûre surfaces, these limestones appear fairly uniform, but on weathered surfaces fine parallel laminations or irregular blotches become prominent. These represent materials of slightly different composition.

Stones River limestone. The limestones most largely quarried for lime in this section belong to the Stones River formation. These are mainly low in magnesia, although there are occasional dolomitic beds. They vary in color from gray to dark-bluish beds with some shaly partings, to the best variety which is a fine-grained, dove-colored stone. This last variety is an almost pure limestone. Fossils are present. Oolite and black chert are to be noted rather commonly.

Chambersburg limestone. The uppermost limestone member of the county is the Chambersburg, which consists of thin-bedded limestones with numerous shaly partings. It is generally low in magnesia. Fossils are abundant and are especially prominent on weathered surfaces in many quarries.

GEOLOGIC STRUCTURE

There are many local folds and faults in the limestones of the county but in general the eroded edges of the oldest strata appear at the south side of the Valley, dipping north or slightly northwest, and successively younger (higher lying) formations are passed over as one proceeds northward. The Tomstown limestone as the basal limestone formation overlies the Cambrian quartzites which form the lower slopes of South Mountain; at the top of the limestone column the Chambersburg limestones dip beneath the Martinsburg shales which form the north wall of the Valley.

DESCRIPTION BY DISTRICTS

In the descriptions of individual areas only those sections are included where quarries are now active or where previously there have been important operations. These have largely centered about the principal towns, which is generally true throughout the entire State except in the case of the largest shipping operations. Equally good stone of similar grades is present in other parts of the county not described.

Shippensburg Area. In the summer of 1930, two quarries were in operation in the Beekmantown limestone east of Shippensburg. The largest of these, on the north side of Burd Run about half a mile northeast of Shippensburg, is known as the Shippensburg quarry. It was being operated by J. C. Showalter. The material is a dense, dark, low-magnesian stone occurring in thick beds with rather numerous calcite veins. Some layers are very gnarly. When fresh, the stone appears to be uniform in texture and composition, but where weathered it is distinctly laminated, dark colored bands alternating with discolored brownish-yellow, sandy-looking bands. The strata dip gently to the northeast. Some bad clay pockets extend downward 10 to 15 feet. The stone was formerly burned for lime, but now is used almost entirely for crushed stone. Some building stone is sold at times. The stone has been used extensively on the State roads. All of the stone is hand picked and hand loaded. The quarry is about 150 feet long, 75 feet wide and has a working face 45 feet in height. The daily capacity of the plant is 250 to 300 tons of crushed stone.

In 1933 this quarry was operated by Walker Bros. of Chambersburg and had a daily capacity of 400 tons.

Huber Coy has been operating a small quarry about three-fourths mile farther east. The stone is similar to that in the Shippensburg quarry. The capacity is only 25 to 30 tons of crushed stone daily.

Newville Area. In 1930, three quarries were being worked in the Newville area in the Stones River and Chambersburg formations. About one-fourth mile west of Newville is the plant of the Spangler Pulverizing Lime and Stone Co. The quarry has been worked for about 25 years, at first for lime entirely, but now mainly for crushed stone, although lime is still being burned. The stone seems to belong to the Stones River formation. In the north part of the quarry there is about 25 feet of high quality gray limestone low in magnesia that is used for lime burning. The balance is higher in both silica and magnesia and darker in color. This stone is crushed. The beds are fairly thick. Near the surface and extending downward to a depth of 5 to 8 feet, the stone is broken badly into small rectangular pieces which are discarded. The clay overburden is from 1 to 3 feet thick. The beds are practically vertical with a strike of N.13°E. The quarry is about 150 feet long and 90 feet wide with a face 35 feet in height and is being advanced along the strike in a westerly direction. There is one kiln in which about 300 tons of lime are burned annually. The daily capacity for crushed stone is about 100 tons.

One mile northeast of Newville is the small quarry of D. H. Heller where lime was once produced but at present only crushed stone. The material is mainly a dark-colored, rather gnarly stone in which the silica seems to be fairly high. Some beds appear to be dolomitic and

others high-grade calcium stone. There are some interbedded shaly layers. Some layers, evidently higher in magnesia, contain many calcite veins. Purple fluorite was noted with this calcite.

Vincent Hamilton has been operating a quarry on the east side of Big Spring Creek just east of Newville since 1926. The stone ranges in color from light gray to dove-color to dark blue. Some of the gray stone is coarsely crystalline and the dove-colored stone is dense and breaks with a glassy fracture. The light colored varieties seem to be very pure limestones, while the darker ones are evidently higher in both silica and magnesia. On weathered surfaces some of the beds are seen to be abundantly fossiliferous with the fossils standing out in relief in excellent state of preservation. Bryozoa, corals, and brachiopods are most numerous. The beds strike N.47°E. and dip 40°SE. The quarry is more or less circular with a diameter of about 100 feet. It is opened in the side of a small hill. The highest part of the working face is about 35 feet. The red clay overburden extends downward in narrow pockets, some of which are over 6 feet deep. Removing the clay leaves numerous limestone pinnacles. Some building stone is produced but almost all the stone quarried is crushed for highway work. The capacity of the plant is 200 tons of crushed stone daily.

At Greason about midway between Newville and Carlisle, Joseph Erford has two lime kilns, where he burns some lime from Beekmantown limestone obtained from the fields. There is an old abandoned quarry nearby.

Carlisle-Boiling Springs Area. The largest limestone operation in Cumberland County is the Bonny Brook quarry of J. F. Sours, about 1½ miles south of Carlisle. The stone is dolomitic, gray to dark blue in color and contains many veins of calcite. Between the thick layers of dolomite there are thin shaly partings showing abundant mud cracks. A few of these layers are true shale several inches in thickness, which must be discarded. The beds strike N.48°E. and dip 45°SE. The overburden is light and clay pockets are neither numerous nor deep. The dimensions of the quarry are about 400 feet long, 225 feet wide, and 75 feet deep. The stone is loaded by steam shovel. There is one large gyratory crusher and a smaller gyratory. The daily output is 400 to 500 tons of crushed stone. At one time lime was burned here and the old kilns are still standing.

An analysis of a limestone from Craighead is given near the close of this chapter.

E. V. D'Invilliers (6, pp. 1519-1520) gives the following description of a quarry being worked for flux in 1886.

"Boiling Springs Quarry.—This is entirely worked for supply of flux to the Katharine furnace at Boiling Springs station on the Harrisburg and Potomac railroad. The quarry is opened along the pike, just back of the hotel and exhibits a fine face of blue-gray limestone, with a smooth texture, and occurring in plates from six inches to a foot and a half thick. It is quite regularly bedded, and while portions of it show the usual variations germane to all limestone exposures, yet a very large proportion of the 60-foot face here exposed furnishes stone suitable for blast-furnace flux. The dip is apparently nearly due east and varies from 20 to 30 degrees."

Camp Hill-Lemoyne Area. At present there are only two active quarries in the Camp Hill-Lemoyne area, both of which are producing crushed stone solely. Until recently the Bushey quarry located about one mile southwest of Camp Hill was worked, but it is now idle and partly filled with water. The strata are interbedded high-lime and magnesian limestones of the Beekmantown formation. The magnesian stone which is dark blue in color seems to predominate. The beds dip southward at an average angle of about 40°.

Hempt Brothers are operating a quarry at Eberlys Mill. The operation was started in 1925, but already a large amount of stone has been removed. The capacity of the plant is 500 to 600 tons of crushed stone per day. The quarry is about 300 feet long, parallel to the dip, 175 feet wide along the strike and has a face from 60 to 65 feet high. The stone worked is a mixture of interbedded low-magnesian, gray to pink, fine-grained marble, gray to dark blue, medium-high magnesian stone and some high-magnesian, gray to dark blue stone with many gash veins of calcite and quartz. One small piece of purple fluorite was observed. All of the beds are fairly thick and they mainly break into more or less rectangular blocks. The strike is N.48°E. with a dip of 35°SE. The overburden of red clay is not heavy and there are few clay pockets. Although the chief product is crushed stone the firm has a hammer mill to produce fine stone for cement blocks.

There has long been active quarrying in the region adjacent to the Susquehanna River in Cumberland County. The Walton quarry along the Susquehanna River opposite the lower portion of Harrisburg is probably the oldest quarry of importance in the county. It extends along the Pennsylvania Railroad for about one-fourth mile. At times, it has been worked for fluxing stone or to obtain stone for burning to lime but more recently it has been worked for road and concrete material. It is now run under the name of Lemoyne Quarries and produces about 400 tons of crushed stone per day. The strata dip steeply to the south with great irregularity throughout the entire quarry. The strata exposed belong to the Beekmantown formation and consist of interbedded high-lime, dove-colored to gray limestones and dark-blue magnesian stones. Both varieties in places contain considerable vein matter but especially the latter. Stylolites are abundant. Black chert segregations are noticeable in places. The old workings have a face varying from 25 to 50 feet in height but a new level 30 feet deeper is now being worked.

Analysis of composite sample of limestone from Walton Quarry near Lemoyne

$CaCO_3$	87.13
$MgCO_3$	10.32
$Al_2O_3 + Fe_2O_3$	.87
SiO_2	3.00

The above analysis represents 11 specimens collected and analyzed by the Bethlehem Steel Co.

J. P. Lesley, former State Geologist, made a detailed study of the chemical composition of the limestone beds in this section and prepared an elaborate report from which the following quotations are taken. This subject is of scientific interest as indicating numerous and frequent changes in sedimentation during Beekmantown time and is of

practical importance as showing the type of stone that may be obtained from this formation which has a wide distribution throughout the State. (See 3, pp. 311-362).

"At a meeting (3, pp. 343-348) of the American Philosophical Society, December 20, 1877, I described the progress of an elaborate investigation which I had instituted for the purpose of determining whether or not any fixed or rational order of deposition could be observed in our Siluro-Cambrian Magnesian Limestone Formation No. II.

"I selected a fine exposure, made by the Walton quarry and rock-cut of the Northern Central Railroad, on the west bank of the Susquehanna river opposite Harrisburg; where a consecutive series of the beds, all conformable, and all dipping regularly about 30° to the southward, afforded a good opportunity for collecting two sets of specimens for analysis, one at the bottom and the other at the top of the cut. Great care was taken to survey the cut, mark the beds (from 1 to 115) and range the specimens in two parallel series; so that any lack of homogeneousness in any bed might be detected by analyses of two specimens, taken from places in the edge of the bed 5 to 30 feet apart, according to the depth of the cut; and sometimes by the selection of a third and intermediate specimen; many of the analyses of individual specimens being also repeated.

"The investigation was continued throughout the winter of 1877-8 by Mr. Joseph Hartshorne, and completed during the summer of 1878 by Mr. S. S. Hartranft; and I now find myself able to bring some of the results to the notice of chemists and geologists in the form of tables; (1) of analyses and (2) of averages.

"The analyses, as reported to me, have been given in full on the preceding pages.

"In the following table (Table I) the relative proportions of Carbonate of lime, Carbonate of magnesia, and Insoluble residue, are given, *and to the second decimal only*.

"Attention is drawn to abnormal beds or analyses by enclosing certain percentages in brackets. The greatest pains were taken to prevent mistakes as to the locus of each specimen; yet, some of these extraordinary percentages *may* be significant of such mistakes. Most of them are probably indicative of actual variations of composition in the beds.

Table I

Bed	Lime Carb.		Magnesia Carb.		Insol. Matter		Thickness	
	Grade	Top	Grade	Top	Grade	Top	Ft.	In.
1	58.35	57.10	36.80	38.25	4.60	4.00	3	0
2	55.60	56.20	38.50	39.75	5.30	3.80	2	9
(a) 3a	89.90	92.00	3.60	4.00	5.70	4.10	3	6
4	93.90	97.05	1.80	1.85	3.80	1.40	4	6
(b) 5	96.40	97.20	1.40	0.70	1.90	2.10	8	1
6	95.50	97.60	1.40	1.30	1.50	1.10	1	0
7	87.10	87.40	3.60	3.70	9.70	9.10	1	0
(c) 8	82.30	87.45	14.50	7.50	3.10	3.90	0	9
(e)(d) 9	68.30	67.60	24.80	27.00	5.50	5.40	2	3
10	90.70	90.40	8.05	8.15	1.90	1.70	2	8
11	97.60	96.70	1.80	1.30	1.00	2.20	8	8
12	66.00	75.80	32.40	19.85	1.60	2.50	5	7
13	96.80	97.20	2.30	1.85	1.20	1.40	3	8
14	95.85	83.70	2.40	11.85	1.80	3.40	12	8
15	92.75	97.30	4.45	1.00	3.40	1.80	4	4

Bed	Lime Carb.		Magnesia Carb.		Insol. Matter		Thickness	
	Grade	Top	Grade	Top	Grade	Top	Ft.	In.
16	97.80	97.10	1.30	2.00	1.10	1.20	2	9
(f)17	96.60	(60.20)	1.10	(33.40)	1.10	(5.90)	2	8
18	97.00	93.50	1.20	4.30	1.40	2.00	1	0
19	65.30	62.30	30.80	34.50	3.50	3.00	1	1
20	96.40	98.70	2.90	0.80	0.70	0.50	2	0
21	76.30	71.75	18.50	24.30	5.30	4.20	1	2
22	93.7	97.4	3.8	1.6	1.9	1.3	2	0
(g)23	65.3	64.3	30.8	28.6	3.4	6.5	1	4
24	94.8	93.1	1.6	1.9	3.9	4.8	6	11
25	68.9	68.9	23.8	23.6	7.4	6.3	0	7
(h)26	90.0	(70.85)	6.8	6.3	3.4	(22.95)	0	9
(i)27	63.3	75.7	28.60	18.1	6.2	5.6	1	11
(j)28	81.25	94.15	6.65	2.15	12.0	4.0	6	5
29	65.0	62.4	29.1	31.4	5.4	5.4	4	1
30	98.9	97.9	1.1	1.30	0.5	0.9	2	7
31	61.0	64.30	27.7	25.20	10.9	10.3	1	0
32	96.7	97.6	1.7	1.0	1.7	1.8	3	0
33	73.3	71.9	12.4	15.5	12.4	10.4	0	2
34	97.6	96.3	1.5	1.2	1.1	1.5	6	8
35	75.20	67.25	18.90	25.65	4.7	5.9	0	10
36	82.9	79.9	13.5	16.9	2.7	4.2	0	9
37	91.0	89.0	5.4	5.8	3.6	3.6	0	10
38	79.7	82.9	16.9	12.3	2.9	2.8	0	4
39	89.7	98.7	8.2	1.6	1.6	0.3	4	6
40	61.5	56.3	33.6	37.2	4.7	6.1	0	10
41	96.9	95.8	1.7	2.2	1.4	1.9	4	2
42	55.6	57.15	35.0	34.95	6.9	6.5	3	2
(k)43	97.8	(91.0)	1.3	(1.3)	1.3	(7.9)	1	2
(l)44	73.6	65.5	22.5	28.2	3.4	4.8	2	3
(m)45	96.2	(96.2)	2.0	(2.0)	2.4	(2.4)	0	3
46	97.2	90.6	1.7	7.6	0.7	1.8	3	6
47	63.4	68.2	29.5	27.1	6.4	3.6	0	10
48	94.3	95.3	1.9	2.2	3.5	2.2	0	5
(n)49	57.8	66.2	33.2	26.9	8.0	5.7	0	2
50	60.4	62.0	32.1	31.7	5.3	5.1	0	6
51	92.9	95.7	3.2	2.9	3.0	1.7	1	10
52	61.4	68.9	31.9	23.7	5.3	7.2	4	0
53	81.1	88.7	10.0	7.0	4.7	3.4	0	5
54	98.2	97.9	1.3	1.2	1.2	0.7	5	2
55	79.8	79.5	10.8	13.4	8.6	6.9	0	11
56	66.9	66.0	24.2	23.2	7.4	9.7	1	0
57	91.6	91.0	2.4	2.3	5.9	6.8	1	10
58	64.8	60.1	27.4	29.9	7.2	8.6	2	0
59	97.1	99.3	1.8	1.3	1.1	0.2	1	10
60	75.1	76.3	20.9	19.9	3.1	2.4	0	10
61	89.3	95.1	1.5	1.8	8.9	2.1	2	4
(o)62	(49.8)	61.9	31.9	28.4	(16.9)	8.2	1	10
63	71.0	72.9	23.8	23.0	6.0	4.9	1	11
64	80.7	87.7	14.2	10.0	2.5	2.3	1	11
65	67.7	70.0	20.9	21.5	10.2	7.8	3	2
66	75.1	79.1	19.2	13.6	5.4	5.8	3	2
67	61.0	61.8	33.6	32.1	4.6	5.9	1	9
(p)68	85.1	96.0	(10.4)	2.3	3.2	1.9	14	0
69	51.7	58.5	32.7	27.4	12.9	11.9	2	10
70	98.2	97.4	1.5	1.4	0.8	0.9	6	6
71	55.6	53.8	33.7	35.4	10.3	10.0	3	8
72	98.1	97.3	1.4	1.6	0.8	1.2	4	6
73	93.9	96.6	3.6	1.6	2.7	2.5	5	6
74	95.6	96.8	1.5	1.2	2.8	2.1	3	7
75	91.3	92.1	2.8	2.2	5.4	5.1	5	0
76	64.9	63.0	23.6	26.7	10.6	9.8	2	3
(q)77	85.5	97.9	(9.9)	1.8	4.5	1.0	1	2
78	56.7	56.0	31.9	31.5	8.5	10.8	2	3
79	86.7	85.2	7.1	8.7	5.0	5.5	3	10
(r)80	79.8	95.9	(9.9)	2.0	9.4	2.6	6	0
(s)81	54.9	56.7	(35.7)	24.0	7.7	18.4	2	7
82	84.7	86.9	10.8	8.5	4.1	4.0	2	8
83	90.7	91.0	8.0	7.6	1.7	1.9	1	9
(t)84	66.8	75.6	(27.2)	16.3	4.4	5.6	6	3
85	97.0	93.7	0.9	4.1	8.6	2.1	7	3

Bed	Lime Carb.		Magnesia Carb.		Insol. Matter		Thickness	
	Grade	Top	Grade	Top	Grade	Top	Ft.	In.
86	95.4	98.9	1.3	1.1	3.8	0.6	6	8
87	52.0	54.1	33.7	28.1	12.5	15.9	11	5
88	96.3	98.4	1.9	1.1	2.2	0.7	2	5
89	59.4	61.6	33.7	31.8	6.1	5.9	5	9
90	97.6	97.6	1.8	1.5	0.9	0.3	0	8
91	68.2	74.1	27.9	23.1	3.9	3.0	0	9
92	98.2	97.7	1.3	1.9	1.2	0.6	2	5
93	58.6	59.2	34.1	35.1	5.6	5.0	1	11
(u) 94	96.7	85.5	1.4	1.4	1.8	12.6	2	0
95	54.8	55.2	31.1	30.6	12.0	12.9	4	0
96	95.8	95.4	2.7	2.2	1.3	1.8	8	0
97	75.2	77.6	17.3	16.4	6.7	4.8	0	8
98	62.0	60.0	29.4	32.8	7.8	6.7	10	6
99	96.3	96.0	1.9	3.2	1.1	0.9	3	0
100	62.2	62.5	29.5	27.4	8.3	7.1	1	8
101	98.2	98.8	1.2	0.8	0.6	0.3	1	4
102	64.4	60.4	30.5	34.2	4.3	4.8	5	6
103	94.7	93.1	4.6	4.8	1.0	1.4	0	11
104	80.2	97.5	13.2	14.7	5.6	4.3	4	6
105	98.2	96.9	1.2	1.6	0.6	1.1	2	3
106	63.4	63.3	31.6	31.7	3.8	4.1	0	10
107	98.2	99.0	1.6	0.5	0.3	0.4	1	9
108	65.0	65.0	29.1	29.6	5.1	5.0	4	10
109	94.8	86.9	2.5	4.3	1.8	7.7	2	0
110	73.1	64.3	16.5	22.3	9.1	11.6	3	0
111	94.5	88.4	2.7	8.3	1.9	2.6	5	6
112	54.4	54.4	35.2	36.2	8.4	7.7	1	7
113	98.1	76.2	0.9	3.7	1.0	18.2	5	6
114	64.6	55.4	26.2	33.8	8.5	9.7	5	6
115	95.1	97.7	1.9	0.9	1.7	1.4	14	0

"Without discussing in detail, at present, this instructive table, several things are evident at a glance, viz: that

1. Alternate strata of limestone and dolomite make up the mass.

2. The dolomite layers carry the most insoluble materials, as a rule.

3. Specimens taken from the top and bottom of the cut (eighty feet apart, or less) differ sometimes as notably from one another as specimens taken from different beds, but as a rule each layer is nearly homogeneous, so far as two or three analyses can show such a rule.

4. Not one of the so-called dolomite layers has enough carbonate of magnesia to make it a true lithological dolomite. They are all merely more or less magnesian limestones.

5. Carbonate of magnesia is not absent from any bed in the whole series."

Pine Grove Furnace Area. There is a small isolated area of Tomstown limestone in the region of Pine Grove Furnace which was once worked. D'Invilliers (6, p. 1521) describes the quarry as follows:

"This Pine Grove quarry lies on the south side of Mountain creek, just opposite Pine Grove. The deposit of limestone has been tested for about one mile N.E. and S.W. from the old Pine Grove bank up to the Red bank; but the development is entirely confined to the one large quarry. The entire product averages about 2,500 tons a year, and is all used for fluxing purposes at the Pine Grove furnace. The dip of the limestone is S.E. at angles of from 25° to 30° and the thickness of the exposure is not far short of 100 feet. The color of the stone is mostly blue and it is quite massive and comparatively

low in silica. The quarry is about 250 x 75 feet, but the main work is carried on at a depth of about 50 feet beneath the surface. Mr. King states that while this limestone contains only about 4 per cent of carbonate of magnesia and 5 per cent of silica, the dolomitic limestone in the ore bank near by contains but one per cent of silica and fully 40 per cent of magnesia. He also notes the fact that the 'fat' valley limestone shows 12 per cent of silica; but in sulphur he finds the valley limestone to contain only .005 per cent as against .125 per cent at Pine Grove."

Analyses of limestone

	1	2
$CaCO_3$	72.321	86.357
$MgCO_3$	20.591	5.236
SiO_2	2.310	8.410
Al_2O_3	.083	.571
Fe_2O_3	4.420	
P	.047	.013
S	.011	.014
Mn_2O_3	.433	None

1. Limestone at Pine Grove Furnace. Rather hard and fine grained; dark bluish gray.
2. Craighead quarry, 2 miles north of Mt. Holly. Rather hard; light gray and brownish gray; more or less coated and seamed with oxide of iron.

The above analyses are taken from Report M3 (7, p. 80).

CALCAREOUS MARL

There are a few deposits of calcareous marl in Cumberland County which have been investigated by J. B. R. Dickey, who has published the following descriptions in Bulletin 76 of this Survey (8, pp. 6-7).

"Just east of Middlesex, three miles northeast of Carlisle, on the farm of Mr. W. R. Simons, on south side of pike and on east side of small stream for some distance and extending back into one or more depressions in fields is a deposit, sample of which showed about 85 per cent carbonate (air dry). The texture is fine and color white. Deposit is well covered with surface soil; depth could not be ascertained with 40-inch soil auger. The deposit was not fully explored or traced.

"On north side of pike opposite the above is a terrace about 20 feet above Conodoquinet Creek which seems to be composed of coarsely granular marl to an undetermined depth. Along the stream marl is solidified, but a short distance back from the bank the material is loose and granular. Deposit more or less reworked; yellowish gray below the surface soil. No samples taken. This terrace, several acres in extent, is occupied by a truck garden.

"On eastern edge of Carlisle on the east side of a small stream (Letort Spring Run) are several acres of marl covered with 6 to 10 inches of dark soil. The bottom of the marl was not reached with a 40-inch auger. Sample tested 84 per cent carbonate (air dry). This deposit is close to railroad and might be developed but it is very little above the level of the stream. On account of the location the land would be held at a high price. Now occupied by truck garden. Origin of this deposit and its full extent not determined.

"On farm of Daniel Witmer, about one mile south of Carlisle is a deposit of marl in a depression across the P. & R. tracks from Letort Spring Run. This is also the same which passes east of Middlesex to join Conodoguinet, so that all these deposits may come from one source,

though examination of the bottom land at several intermediate points showed no marl. The full extent of this last deposit may not be known but it did not seem to cover more than a half acre. The depth was over three feet. Sample tested was very white and fine. Practically all of it passed a 60-mesh screen and 90 per cent passed 100 mesh Analysis shows over 96 per cent total carbonate. This is the purest and finest sample of marl examined. The deposit has never been utilized and is probably too small for commercial development. It could be utilized locally, however, until the water became troublesome as the excavation deepened. The water table is rather high.

"On the Harvey Line farm and adjoining property three miles west of Carlisle marl occurs in a bottom along a small stream. Bottom used largely as pasture and covered with 6 to 8 inches of brown soil. Depth of marl over 3 feet; air dry sample carried 84 per cent lime. Water table rather high but marl could be developed for local use.

"On the Lehman farm, ½ mile northeast of the above deposit, marl occurs along the stream. The surface soil has been eroded from this deposit in places. Its extent and analysis were not determined.

"On the farm of W. McKeehan, one mile south of Alterton, west of Carlisle, is a considerable body of marl occupying a depressed area. Sample analyzed only 48 per cent total carbonate. Sample from Andrews' farm adjoining tested only 51 per cent. These samples were low in lime but the marl was easily accessible, fine in texture and comparatively dry so might be used economically on nearby fields."

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DAUPHIN COUNTY

CANADIAN-ORDOVICIAN LIMESTONES

All of the known outcropping limestones of Dauphin County are located in the southern portion and belong to the Canadian-Ordovician series. It is possible that the Helderberg limestones may be present in Manada Creek Valley, but they have not yet been recognized there. With the exception of a few small areas of limestones interbedded with the shales and slates of the Martinsburg formation, the limestones are in two distinct bands. The most northerly one extends from Susquehanna River in the south part of Harrisburg eastward to about 2 miles east of Rutherford Station. The Reading Railroad traverses this belt which contains Paxtang, Boyd, and Rutherford Station. This band is over 2 miles in width at the river, and gradually narrows eastward. It occupies a distinct valley enclosed on both sides by the Martinsburg shales that are more resistant to erosion and consequently form higher ground.

The second and more southerly limestone band extends entirely across the county from Susquehanna River to the Lebanon County line. From Steelton, the band extends almost due east to Swatara Creek and is about three-fourths mile wide. From there it widens to about 4 miles at the Lebanon County line. Steelton, Hummelstown, Swatara, Hershey, and Hockersville are all situated in this limestone band. Martinsburg shales bound this limestone area on the north and Triassic red shales and sandstones on the south.

Limestone quarries have long been worked in Dauphin County to supply building and fluxing stone and for lime burning. Most of these operations were small and have long since been abandoned. Other quarries have been operated more or less continuously for 100 years or more and are now being worked more extensively than ever before. The principal quarries have been and are now being operated for fluxing stone or for high grade calcite stone for chemical lime or for Portland cement. In addition a large tonnage of crushed stone has been produced in recent years. Practically all the limestones of the county are satisfactory for crushed stone. D'Invilliers (see bibliography at close of chapter) in 1886 described 32 limestone quarries in the county. At present only 11 are in operation or only recently closed and hence considered worthy of description. The principal quarry districts are at Steelton, Hummelstown, Swatara and northeast of Hershey.

Nearly all of the limestones in the two broad limestone bands belong to the Beekmantown formation which is composed of alternating series of high, medium, and low magnesian rocks in which the silica content also varies a great deal. Much of the limestone is sufficiently low in magnesia to be serviceable for the manufacture of Portland cement and high enough in lime to warrant its shipment to cement plants for raising the lime content of the mix. The chief difficulty, however, is to quarry the different grades separately, as they are everywhere interbedded. A property which was prospected for high-calcium limestone about 3 miles southwest of Hummelstown showed much less magnesian stone in the Beekmantown than is usually found and yet

it is doubtful whether it would be profitable to work a large quarry there for high-calcium stone, due to the interbedded magnesian strata.

At the northern side of the limestone belt and next to the Martinsburg shales there is a narrow band of stone that is composed of a series of unusually high calcium limestones which have long been extensively worked in the vicinity of Annville and is generally known throughout the Lebanon Valley as the Annville limestone. It is over-

Fig. 12. Limestone areas in Dauphin County.

1. Hoffman Brothers and Wilson. 2. J. M. Whittock. 3. Bonnymead Farms. 4. Bethlehem Mines Corp. 5. Highspire Quarries (Hocker quarry). 6. Union Quarries Corp. 7. George Ebersole. 8. H. E. Millard. 9. Reinhard Lime Works. 10. Garosi and Brancazi. 11. Hershey Estates. 12. Annville Stone Co. 13. H. E. Millard.

lain by argillaceous carbonaceous limestones. Because of overturned strata these normally overlying beds actually form the footwall to the Annville limestone horizon in the Hershey region and eastward through much of Lebanon County. These combined high-lime strata and the overlying shaly limestones are grouped together in a single formation

which constitutes the Jacksonburg formation in the Lehigh Valley and is called the Conestoga formation in Lancaster County. Stose (6) proposes the name of Leesport for these limestones in Dauphin County that form a narrow northern band that extends from the Lebanon County line westward to Swatara Creek about one mile southwest of Hummelstown and in which the high lime strata have been extensively worked northeast of Hershey and at Swatara. He also refers a narrow band about $2\frac{1}{2}$ miles long located at the south side of the northern broad limestone band just east of Harrisburg to this same formation. In this same limestone valley which passes eastward from South Harrisburg he maps a narrow band of Chambersburg-Stones River lying next to the Martinsburg shales, bounding the valley on the north.

The youngest limestones of the county are of basal Martinsburg age and are found in four narrow east-west trending bands within the Martinsburg formation together with limestone beds that Stose (7, pp. 638-641) considers of Black River, Chazy and Beekmantown age. These are located as follows: one is exposed in the small tributary of Paxton Creek a short distance north of the State Insane Asylum; another, along Paxton Creek about a mile to the north, a third, crossing Paxton Creek a short distance southwest of Linglestown; and a fourth, crossing Beaver Creek about 2 miles southeast of Linglestown.

All of Dauphin County has been subjected to intensive compressive forces acting in general in a north or north-northwest direction and throwing the once horizontal beds into folds that trend east-west or slightly northeast-southwest. Many of the major folds have been overturned so that both limbs of the folds dip south or southeast. The most general dip of the beds is south-southeast. However, there are places where the folding has been less intense and northerly dips are common. In few places are beds found approximately horizontal. Few faults are big enough to cause serious problems in quarrying.

DESCRIPTION BY DISTRICTS

The descriptions of quarries are limited almost entirely to present operations. These places have been worked because of the grade of stone obtainable, the accessibility to the railroads, good highways or to the plants where they have been utilized, or the low cost at which the stone could be quarried. Since quarrying has been carried on for a long time the assumption that the most favorable locations have been worked is probably correct and yet the writer is convinced that there are other desirable quarry locations where good stone will be obtained when market conditions demand new quarries.

Paxtang Area. There has been active quarrying of limestone in the Paxtang region. D'Invilliers (2) in his investigations in 1886 found 10 quarries, of which 6 were in operation. The stone was then used for burning lime, for flux, and for building stone. At present only 2 quarries and plants are active, one producing crushed stone only and the other burning lime.

The largest quarry now in operation is that of Hoffman Brothers & Wilson. It is located on the south side of the Reading Railroad, about one-fourth mile southeast of Paxtang. D'Invilliers describes this quarry and says it was opened in April 1886. At that time, the output all went to the Paxton furnaces in Harrisburg as fluxing stone. At present only crushed stone is being produced although by careful

quarrying some low silica stone suitable for flux could still be obtained. The upper beds exposed are mainly high-calcium, gray to olive drab limestones, the lower and more abundant ones are gray to dark-colored magnesian stone. They belong to the Beekmantown formation. The west quarry face shows a beautiful symmetrical syncline and anticline, the two folds occupying the entire west face which is about 500 feet long and 90 feet high. The axis of the folds is roughly east-west. There is much vein matter in the stone, especially in the magnesian strata. A little fluorite was observed in association with the white calcite. The plant is well equipped and capable of producing a large daily tonnage.

Until recently, J. M. Whittock operated 3 quarries along Spring Creek, just south of Paxtang. Two of these were in line and practically continuous in the bluff bordering the creek and the other one lying to the north was much deeper, and extended well below the water in the creek. The two on the south side of the creek have a combined face about 1000 feet long and 65 feet high in places. The other one had a working face of about 600 feet. This opening was flooded by a large stream of water entering the quarry and rendering it impracticable to continue operations. At an early date these quarries were operated for furnace flux and in recent years for both fluxing stone and crushed stone. The strata are considerably disturbed so that it is difficult to determine the structure although the general dip appears to be to the south and southeast. The stone varies from a light-colored, high-calcite marble to a dark-colored, almost equally high calcite stone, to a dark-colored, hard, tough magnesian stone. Analyses of stone from these quarries are given in the table of analyses. The clay overburden was heavy and clay pockets bad, yet because this was one of the first quarries in the region to produce crushed stone, the product was used extensively in the immediate region and shipped considerable distances by rail.

On the north side of the William Penn highway, about one-fourth mile northeast of Boyd, limestone of the Beekmantown formation has long been quarried for fluxing stone and for lime-burning. The quarry now belongs to the Bonnymead Farms and is worked mainly for stone for burning, although crushed stone has also been produced. There are 4 lime kilns close to the quarry. The opening exposes both high-grade, gray to dove-colored, high-calcium stone as well as darker colored high magnesian stone. Only the low magnesian stone is now being quarried for lime burning. The strata have been greatly folded and several beautiful folds can be seen, including one overturned syncline. The strike is east-west.

Steelton District. The most extensive single quarry operation in Dauphin County is that of the Bethlehem Mines Corporation (subsidiary to the Bethlehem Steel Co.) located along Susquehanna River just southeast of Steelton. The quarry rock belongs to the Beekmantown formation and consists of interbedded stone of varying chemical and physical properties. Most of it is gray in color, fairly high in $MgCO_3$, and hard although rather badly shattered. Folds and faults in the quarry result in changes in both strike and dip. In general, the beds have a northeast-southwest strike and dip to the southeast at angles of 20° to 30°. Solution has produced small caverns in which there is some cave travertine. The quarry is a hillside opera-

tion with the quarry floor only about 20 feet above the level of the water in the river. The length is about 1600 feet, breadth 500 feet, with a height of face of about 80 feet. The thickness of the overburden of clay and rotten limestone is decidedly variable. The average thickness is about 12 to 15 feet but in a few places it exceeds 30 feet. The quarry is equipped with modern crushing, screening, and washing facilities. The stone is loaded by electric shovels into trucks and hauled to the crushers. The stone from 2½ to 6 inches in size is taken to the Steelton blast furnaces nearby to be used as flux. The smaller sizes are sold as washed commercial crushed stone and sand. The estimated annual capacity of the plant is given as 480,000 tons of fluxing stone and 300,000 tons of commercial stone. The total production since acquisition by the present company in 1917 has been 2,860,000 tons of fluxing stone and 1,140,000 tons of commercial stone. Some carload analyses are given on a later page. The following represent two of the distinct varieties.

Analyses of medium and high magnesium stone, Steelton quarry

	High Mag.	*Medium Mag*
$CaCO_3$	60.63	73.56
$MgCO_3$	35.55	21.55
$Al_2O_3 + Fe_2O_3$	1.00	1.27
SiO_2	2.00	3.81

Just east of the Bethlehem Steel Company's property is the Hocker quarry of Highspire Quarries. This quarry is along the west side of Laurel Run about a mile north of Highspire. It is an old quarry that was long worked for lime and for building stone. The fine old houses in the vicinity built of stone from this quarry furnish evidence of the satisfactory material obtainable here. At present the product is almost entirely crushed stone although a limited amount of building stone is also produced. Most of the stone separated for building purposes is rather thin-bedded, only a few inches in thickness. The quarry is about 250 feet long, 130 feet wide, and the face is about 40 feet high. The stone belongs to the Beekmantown formation and, as common in most places, consists of alternating beds of different composition. It is gray to dark blue with some carbonaceous matter concentrated along the bedding planes. In general the high-calcium stone is gray and decidedly crystalline, and the more magnesian beds dark blue and dense. The magnesian beds have been fractured and these openings are filled with white calcite and dolomite. The present face shows mainly rather high magnesian stone. Much of it is thin-bedded. The strike is approximately east-west and the dip from 18° to 30° south. The capacity of the crushing plant is about 150 tons per day.

Analyses of stone from Hocker quarry, Highspire

	1	2	3	4	5
CaO_3	88.13	67.43	82.66	97.24	75.57
$MgCO_3$	6.62	28.88	9.99	0.50	19.29
Al_2O_3	--------	--------	--------	--------	0.85
Fe_2O_3	0.52	0.62	0.60	0.185	--------
SiO_2	3.94	2.64	6.22	2.012	4.54

1. Light colored stone.
2. Medium colored stone.
3. Dark colored stone.
4. High grade stone occurring in a few layers in a small nearby quarry.
5. Average of 9 samples taken at approximately equal distances.

Analyses 1 to 4 made by I. S. Hocker, 5 by Bethlehem Steel Co.

Hummelstown Area. A number of quarries have been worked at one time or another north, south, east, and west of Hummelstown. The only one now working close to the town is that of the Union Quarries Corporation owned by Herman Wagner and located on the north bank of Swatara Creek directly north of the town. The quarry face is parallel to the creek and is about 350 feet long and 65 to 70 feet high. It has been advanced northward into the hill about 175 feet and is being extended northeastward along the strike. The beds strike N.57°E and dip 22°SE. The quarry contains several grades of stone ranging from a compact gray stone fairly high in calcium and low in magnesia to a dense, hard, dark-blue, high-magnesian variety with many gash veins of calcite and dolomite. The beds are fairly massive and the stone breaks into angular masses. The product is crushed stone of a good grade. The stripping varies from 5 to 8 feet with no deep clay pockets.

On the south side of Swatara Creek north and northeast of Hummelstown, there are several old quarries that appear to contain the Annville ledge of high calcite stone. They were worked to obtain stone for lime burning. The quarries also furnished some stone for building purposes and some fluxing stone. In all the quarries the strike is northeast-southwest or east-west and the dip to the south or southeast.

Indian Echo Cave, one of the most important caves in the State, is located along the north bank of Swatara Creek about 1 mile southwest of Hummelstown. It originated by solution of Beekmantown limestone. The cave formations are very beautiful.

George Ebersole is operating a crushed stone quarry along the Hummelstown-Middletown road about midway between these towns. The stone is of Beekmantown age and consists of interbedded high-calcite gray stone and medium to fairly high magnesian stone darker in color. Most of the stone is fairly massive but there are some thin-bedded strata. Considerable shiny black carbonaceous matter is developed along some of the bedding planes. The beds strike north-south with a dip to the east of 12° to 15°. The quarry is about 350 feet long by 150 feet wide with a quarry face about 60 feet high. The capacity of the plant is about 400 tons in 30 hours.

In 1924-1925 the Lawrence Portland Cement Co. prospected several farms lying just north of the Ebersole quarry by putting down 20 churn drill holes to depths of 25 to 134 feet and analyzed the drill cuttings every 5 feet. The beds in the region are flat to gently dipping in various directions. The averages of the holes sunk to depths of 100 feet or more are as follows:

Average analyses of churn drill holes on farms north of Ebersole Quarry

$CaCO_3$	90.02	92.43	90.12	92.04	90.24	80.45	82.63	87.26	79.16	91.03
$MgCO_3$	4.11	4.04	4.57	5.22	4.78	4.72	5.11	4.05	4.53	5.34
$Al_2O_3+Fe_2O_3$	1.81	1.16	1.60	0.89	1.50	3.11	2.73	2.26	3.92	1.13
SiO_2	3.11	1.52	2.85	1.01	2.65	10.59	8.49	5.76	11.41	1.48

These results are of especial interest as they indicate the quality of stone that may be expected in the Beekmantown formation of Dauphin and adjoining counties. One cannot say that these analyses are typical but it is probable that similar results may be secured

in other areas of Beekmantown limestone. The details, which cannot be presented here, showed that by careful quarrying, stone of better grade than that given in the above averages might be obtained.

On the west side of Swatara Creek about 2 miles south of Hummelstown is the old Stover quarry, which is now idle. High calcite and low to medium magnesian Beekmantown limestone was long worked here to be burned into lime. Analyses of some samples from this quarry are given in the table of analyses at close of this chapter.

Swatara Area. For at least 50 years and perhaps much longer there has been considerable limestone quarrying in the immediate vicinity of Swatara. Most of the openings are on the south side of Spring Creek but quarrying has been done in two localities lying to the north. The stone from this section in the past was used almost entirely for flux and for lime. At present there are only 3 working quarries in this section and nearly all the stone quarried is burned for high grade lime, hence only the best grade of stone is used. One small quarry is producing a marble for building purposes. This is the band of Annville limestone which passes through the district just to the north of the Reading Railroad. The H. E. Millard quarry is opened in this band. Due to folding or possibly faulting, part of the same bed is repeated farther north in the quarry of Reinhard Lime Works, and apparently the same bed is exposed to the south in the quarry of Garosi and Brancazi. The actual structure existing in this region has not been fully worked out by the writer due to lack of time. Some of the quarries show close folding and fracturing.

The largest quarry in the area is that of H. E. Millard, located just to the north and northwest of the village and between the main highway, Route 422, and Spring Creek. This plant was purchased from the W. T. Bradley Co. in 1929. At present the work is confined to that portion of the property lying to the west of the road leading to Union Deposit. This opening was started in 1926. Previous to that period quarrying was done east of the road, these openings now being largely filled with water. There is still stone there that can be economically obtained and the work will be resumed when market conditions warrant. The active quarry is about 700 feet long parallel to the strike of the strata, is 150 feet wide, and 60 feet deep to the main quarry floor. A deeper 18-foot cut was started in 1931. The beds are regular, strike N.55°E., and dip 68°SE. The stone is a soft gray crystalline limestone occurring in rather thick beds. It is a little darker in one part of the opening and perhaps very slightly lower in its calcium content. The stone is fairly typical of the Annville stone as developed in the Annville district of Lebanon County, but not as thick. The footwall rock is dark in color and shows the presence of carbonaceous matter. It is commonly called the ''black rock.'' It is higher in both silica and magnesia and therefore not used for lime. Some of it has been quarried at one part of the quarry for crushed stone. The hanging wall consists of a dark colored rock that is higher in both silica and magnesia than the gray stone and yet purer than the footwall stone. Interbedded with the typical hanging wall strata, there are some beds of fine grained white to light gray banded and mottled marble such as has been noted in some of the Beekmantown limestone quarries in the vicinity of Paxtang. The stone is hand loaded. It is passed

over a grizzly and everything over 4 inches goes to the lime kilns. The smaller sizes are sold to the cement plants or as crushed stone for highway and concrete work. The lime plant is a well equipped one in every respect. There are 8 new upright kilns. Across the road to the east, there are 7 pot kilns, built several years ago.

Reinhard Lime Works operates a small quarry and 4 lime kilns about half a mile north of Swatara on the east side of the Swatara-Union Deposit road. The quarry is about 125 feet in diameter and has a face 40 to 50 feet high. The beds strike N.53°E. and dip 18°SE. The principal stone developed is a gray high-calcite stone that seems to be the Annville ledge. It is underlain by the "black rock" which shows black shiny carbonaceous matter along the bedding planes and appears to be higher in both silica and magnesia. The beds average about 1½ feet in thickness. The clay overburden and clay pockets are serious obstacles in quarrying.

Just to the east of the working Reinhard quarry, there are several other small openings along the same strike. Three of these quarries were described by d'Invilliers in 1886. They contain stone similar to that described above.

Recently a small quarry has been opened south of the Harrisburg-Reading highway and just east of the Swatara-Hockersville road by Garosi and Brancazi. The opening is small and only about 18 feet deep. The quarry has been worked for building stone and the refuse will be crushed for road work. One small building in the west part of Hershey constructed of this stone is very attractive. The stone is a light gray to light drab, somewhat mottled, fine-grained high-calcite marble in fairly thick beds that are nearly horizontal. Some of the weathered portions are light pink in color. If there is a sufficient thickness of this stone it gives considerable promise as a marble quarry. So far it had not been investigated beyond the present opening.

Hershey Area. There are many outcrops of high grade limestone in Hershey. These weather very white and are particularly attractive. At present there is only one small quarry working within the borough limits. The principal quarrying is done northeast of the town from the borough line to the Lebanon County line.

The Hershey Estates has recently opened a small quarry in the southeast part of Hershey to obtain some building stone. The opening exposes a thickness of about 10 feet of beds that are not far from horizontal. The stone is a beautiful light gray to drab, compact, fine-grained marble that on weathering becomes somewhat stained with light yellow blotches, making a pleasing effect.

The Annville Stone Co. has an extensive quarry on the north side of the Reading Railroad about a mile northeast of Hershey. There are two openings which are connected by a tunnel about 600 feet long. From the east end of the old quarry to the west end of the newer quarry the distance is almost 3000 feet. The old (eastern) quarry was worked down to a depth of 40 to 50 feet and the newer opening has been worked to a depth of about 100 feet at the deepest point. Through the tunnel a great deal of stone will be removed from the floor of the old quarry.

In order of age, the strata of the region belong to several different series. The oldest are the (1) dolomitic beds that appear on the

south side of the quarry openings. The next is a series of (2) high calcium gray limestone beds, generally known as the Annville limestone. This is followed by (3) dark colored limestones that contain considerable graphitic matter, and next are the (4) shaly limestone beds that form the foot-wall in the quarry openings. On the hills to the north are the (5) Martinsburg shales, representing the youngest strata of the district.

There has been considerable folding and faulting of the beds since they were laid down as horizontal layers in the ocean over 400,000,000 years ago. The major structure is a northeast-southwest fold which has overturned the strata, causing them all to dip to the southeast at an angle varying from 33° to 39° and reversing the order of position so that the oldest beds, the dolomite, are on top and the successively younger beds are beneath.

In addition to this major folding there has been some minor folding, but usually not enough to change the continuity or regularity of the beds. A specimen of the black limestone showing a finely developed fold involving about 6 inches of stone was picked up toward the west end of the quarry. Two folds of more significance are described below.

There has been some displacement of the beds by faulting. In the main, these faults involve movement that is measured by inches or by a few feet. A few, however, are of sufficient magnitude to be rather serious.

In the working of the quarry, the pure limestone alone has been sought. This has been worked from the outcrop and followed along the strike. The width of the quarry is determined by the breadth of the outcrop between the shaly limestone foot-wall on the north and the dolomite hanging wall on the south. Some dolomite is removed, but as the thickness increases toward the south, due to the dip, it soon becomes impracticable to remove this increasing overburden.

An unusual feature of the property are two marked constrictions in the limestone band by which the foot-wall of shaly limestone extends southward in secondary folds whose axes are almost at right angles to the large folds previously described. There has been a definite pinching out or squeezing out of the limestone, thus bringing the hanging wall of dolomite very close to the foot-wall of shaly rock. One of these folds occurs just east of the eastern end of the main quarry and the other is about 225 feet from the west end of the old quarry. The character of the folding of the first one is shown well in the tunnel recently driven to connect the old and new quarries.

These two folds are unique as it is not often that a layer of limestone is squeezed out in this manner. They interfere with the regularity of the quarrying and if the quarry operations are ever extended to unite all portions of the two quarries, it will probably mean the removal of a small amount of the useless foot-wall. However, they are not serious obstacles and do not greatly decrease the amount of limestone in the property.

In the working quarry there is a definite band of black limestone between the shaly foot-wall and the good gray limestone. There is much carbonaceous matter through the rock, giving it its black color, and when the rock is broken along its bedding planes, the surfaces of the rock are seen to be coated with a dense glossy covering of

graphitic matter. The writer is informed that this rock analyzes from 90 to 94 percent $CaCO_3$, perhaps averaging about 92 percent. It seems that the thickness of this black limestone varies somewhat. In the main quarry almost directly north of the crusher house, it is only about 2½ feet thick, whereas in the western end of the quarry it is almost 10 feet thick. There is no evidence to show whether it still further thickens toward the west in the undeveloped property or whether it is reduced in thickness.

The output of the Annville Stone Co. is mainly shipped to the cement plants in the Lehigh Valley. The stone is washed to remove any clay that may have come down from the surface.

H. E. Millard is working along the same ledge of Annville limestone directly east of the Annville Stone Co. property and extending to the Lebanon County line. The opening along the strike is about 1100 feet long and 350 feet wide. The stone is the same as described above, except the dip of the beds is somewhat steeper, up to 50°, than in the Annville Stone Co. quarry. There are 13 pot kilns in this property supplied with stone from this quarry. The lime is of chemical grade and is largely used in chemical manufactures.

Other limestone areas in Dauphin County. So much attention has been given to the Annville stone in the eastern part of the county that the stone of poorer quality has been neglected. There are many places favorable for quarry sites in the Beekmantown limestone areas south and east of Hummelstown, about Hockersville, and east of there to the county line. There are old quarry openings in several places where stone was once quarried for building and burning for agricultural lime. Road stone of good quality could be produced in many places in that part of the county. The Martinsburg formation contains some infolded limestones in the region north and northeast of Harrisburg. These limestones consist of rather thick beds of limestone breccia or edgewise conglomerate and thin beds of fine grained limestone of uniform texture interbedded with the Martinsburg shales and slates. The Second Geological Survey geologic map shows four limestone areas within the shales but represents them as of the same age as those in the limestone valleys to the south. In two of these areas, these limestones have been quarried on a small scale and burned for lime. These localities are along the small stream just north of the Glen Gery Brick Yard which itself is just north of the State Insane Asylum and along Paxton Creek about one mile farther north. A specimen from the Paxton Creek area analysed by the Pittsburgh Testing Laboratory gave the following results:

Analysis of limestone one mile north of Glen Gery Brick Yard, Harrisburg

	Per Cent
SiO_2	12.70
Al_2O_3	1.85
Fe_2O_3	.86
TiO_2	.20
CaO	45.90
MgO	1.00
Loss on ignition	36.90
SO_3	trace

The two additional areas of limestone mapped lie about two-thirds mile to the southwest and about 1½ miles southeast of Linglestown.

In addition loose pieces of limestone in the fields bordering the Linglestown—Fort Hunter road and elsewhere south of Linglestown indicate that occasional limestone beds within the Martinsburg shales of Dauphin County are not uncommon. Recent studies lead G. W. Stose (7, pp. 638-641) to believe that these limestones are infolded basal Martinsburg, Black River, Chazy and Beekmantown in age. With the county otherwise well provided with good limestones in thick masses, it does not seem that these limestones can be regarded as of any economic importance.

Additional analyses of Dauphin County limestones

	1	2	3	4	5	6	7	8a	8b
$CaCO_3$	82.69	83.41	87.01	80.77	75.57	74.72	73.88	94.44	90.36
$MgCO_3$	15.21	13.72	10.11	9.99	19.29	21.42	21.51	3.89	7.59
Al_2O_3	1.04	1.24	.70	2.15	.85	----------	1.28	.36	.33
Fe_2O_3	----------	----------	----------	----------	----------	----------	----------	.30	.31
SiO_2	1.81	2.60	1.98	7.86	4.54	3.02	3.66	2.02	1.96

1. Quarry of Annville Quarry Co., 1 mile northwest of Palmyra. Average of 42 cars shipped to Steelton during 1917.
2. Spring Creek Limestone Co. quarry, Swatara. Average of 60 cars shipped to Steelton during 1917.
3. Bradley quarry, Swatara. Average of 22 cars shipped to Steelton during 1917.
4. Abercash quarry, 1 mile east of Hummelstown. Average of 8 samples.
5. Hocker quarry, 1 mile southeast of Steelton. Average of 9 samples.
6. Cumbler Property, ½ mile southeast of Steelton. Average of 14 diamond drill cores.
7. Quarry of Bethlehem Steel Co., Steelton. Average of shipments during 1918.
8. Beekmantown limestone. J. T. Whitock quarry, Paxtang. (a) average of 7 cars shipped in 1915. (b) average of 18 cars shipped in 1916. Above analyses made by Bethlehem Steel Co.

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DELAWARE COUNTY

There are no limestones in Delaware County. The rocks of this county consist entirely of ancient schists and gneisses, overlain along Delaware River by alluvial deposits of clay, sand, and gravel.

ELK COUNTY

The limestones of Elk County are of little importance, although there are several horizons at which limestone has been found. These are, in ascending order, the Benezette (Pocono), Vanport, Lower Freeport, Upper Freeport, and Johnstown Cement Bed. At one time or another, it seems that limestone has been quarried from each of these horizons, but only in a small way. The Vanport is the most extensively developed in the county and has been quarried in a number of localities. In recent years there have been no continuous operations and the indications are that the utilization of the limestones of the county will decrease rather than otherwise.

VANPORT LIMESTONE

The Vanport is of good quality as a general rule, but all of the other limestones are of poor grade, almost invariably high in silica. The Vanport is the principal limestone of Elk County although even it is of very little importance. During the summer of 1929 it was examined in a number of places but lack of time prevented the writer from tracing it throughout that portion of the county where it is supposedly present. On the geological maps of Elk and Cameron counties by C. A. Ashburner published in Report RR of the Second Geological Survey of Pennsylvania in 1881 the outcrops of the Vanport (Ferriferous) limestone are shown by dark blue lines. In some of these places later investigations have definitely proved its absence. Inasmuch as the Vanport in this section is discontinuous it is highly probable that detailed work will show many local errors in that it may be absent where shown and present in small patches where not represented on the map.

The Vanport in Elk County is much less valuable as a horizon marker for the identification of the coal beds than in the counties to the southwest because of its discontinuity. In some sections the horizon where it should be found is occupied by nodules of iron carbonate or calcareous chert but in other regions there is nothing to indicate its presence. Its absence is due mainly to non-deposition of calcareous matter at the time that it was being precipitated in other sections but in some cases subsequent solution explains its non-appearance now.

At the time of the writer's visit only a few quarries were being operated and all of them only intermittently to obtain stone for burning or grinding for agricultural purposes for local consumption. The stone is less pure than in the counties to the southwest although in physical appearances it is similar. On the weathered surfaces and occasionally on the fresh fractures one finds the typical crinoid stems, brachiopods and corals, most of them in fragments. Some layers are gnarly and these are usually free from recognizable fossils. Most

of the beds are compact, bluish to gray in color and break with a glassy conchoidal fracture.

The most northerly quarry operation of the Vanport is that of R. W. Markert, Wilcox P. O., about half a mile east of Rasselas station. He has opened two quarries, one where the flat limestone caps the hill with practically no overburden and another in a ravine about 200 yards to the east. In the first the stone is badly weathered and broken into small blocks. The stone being quarried is about 40 inches thick. The product of this quarry is ground in a Day pulverizer and sold to the farmers for agricultural purposes. The operator received $4.00 a ton for the material. The operation is a very small one and will probably be abandoned soon.

The second opening has been operated to obtain stone for burning for agricultural lime but may not be worked much more because of the increasing overburden. The stone is less weathered and much more massive. A thickness of 39 inches was measured in the quarry but the base was not exposed. The upper 6 inches of the bed is iron-stained but not as ferruginous as the usual iron carbonate layer. This is probably the lower bed described by Ashburner in the following section while the beds being worked in the first quarry is the upper layer although the interval between the two seems to be greater than that given by Ashburner. The writer failed to find any exposure showing the two layers.

Ashburner's section given in (3, p. 73) taken from a quarry near Rasselas in operation in 1879 is as follows:

Section of Vanport limestone near Rasselas

	Ft.	*in.*
Gray slate		
Rotten greenish gray limestone	3	0
Gray shale	8	0
Iron ore	1	0
Hard massive blue limestone	7	11
Slate	1	6
Coal	1	4

Ashburner shows on his map several areas of Vanport (Ferriferous) southwest of Wilcox but so far as known there is no true limestone there, the horizon being represented by calcareous chert and nodules of iron carbonate.

In the vicinity of St. Marys the Vanport should outcrop near the tops of the hills and according to report it does. Near the top of the hill in the north part of the town a little stone was one time obtained by removing a thin overburden of shale and clay. Some fragments of typical Vanport were found there after considerable search.

The principal areas of Vanport limestone in Elk County are found along Little Toby Creek and its tributaries in Fox and Horton townships. The formation is probably continuous or nearly so throughout this section and according to report it has been quarried on a small scale in many places where it outcrops along the sides of the hills, especially in the vicinity of Kersey and Kylers Corners. About two miles south of Kylers Corners, Nils Stranberg operates a small quarry close to the railroad. The exposure shows a thickness of about 5 feet. The stone is burned for agricultural lime for use in the immediate vicinity. W. L. Eddings has worked a small quarry for his

own supply of lime and another quarry has been recently worked in the Challenge farm.

In the hillside quarry of the Shawmut Brick and Tile Company just south of the village of Shawmut the Vanport limestone is exposed. Where measured, it is 59 inches thick. The stone is massive and grayish-blue in color with bedding planes scarcely perceptible. A thin band at the top is decidedly ferruginous. Some fragmentary fossils can be seen on the weathered surfaces. While the quarry was being worked for shale for the brick and tile plant the limestone layer was undermined and as it broke off in large blocks and tumbled down the pieces were collected, ground in a nearby crusher and sold for farm use as pulverized raw limestone. Since the brick and tile plant has been idle the limestone operation has ceased and the owner of the crusher contemplates moving the crusher to a new location. Quarrying the limestone at this point by itself would be too expensive on account of the heavy overburden.

Ashburner describes some other localities along Little Toby Creek where quarries were in operation in 1879 in the following quotations: (3, p. 209)

"The Ferriferous limestone is exposed on the eastern bank of the Toby creek, about 2000 feet south 70° east from P. W. Hayes' house, near Kyler's Corners. The elevation of the top of the limestone is 1570 feet. The bed is 6 feet thick, and immediately underneath it, is exposed 1 foot of carbonaceous black slate, underlaid by gray shale and slate."

"The Ferriferous limestone is also exposed in one of the head branches of Saw-Mill run, near the road between Kyler's Corners and Weedville, and about a mile and a half south-east of the former locality. The stone quarried from this bed has been burned by Judge Kyler, and is said to produce a superior lime."

"On the hill east of Brockport, and alongside the road, the Ferriferous limestone has been quarried, at an elevation of between 140 and 150 feet above the Brockport store. The face of the limestone has been exposed 7 feet high and 50 feet long. The lower and upper parts of the bed are composed of shaly, very ferruginous, and highly fossiliferous layers, and are of a darker color than the more massive central part, which measures from 4 feet to 4 feet 6 inches thick." (3, pp. 239-240)

In the southeastern part of the county in the valley of Bennett Branch of Sinnemahoning Creek the Vanport is likewise well developed. Inquiry failed to get any information concerning any quarrying operations within recent years. Unquestionably some Vanport limestone could be obtained in the vicinity of Caledonia and Benezette but it is doubtful whether it would be profitable to open any quarries under present conditions even for local use. A short distance northeast of Benezette, Ashburner observed the limestone and gives the following description (3, p. 254):

"The Ferriferous limestone is exposed at a number of localities along the summit, and has been quarried and burnt for lime, which has been used extensively as a cement and a fertilizer. Its thickness varies from 5 to 10 feet. The bottom of the limestone on George W. Winslow's farm was found at an elevation of 1610 feet. The stone is very hard, massive, and brittle, in places very ferruginous, and con-

tains a number of imperfect fragments of fossil shells. At this point the face of the bed measured 7 feet thick."

"At Winslow's lime quarry, alongside of the kiln, the bed will probably be found at least 10 feet thick, when quarried further into the hill. In the center of the bed there is very frequently found 1 foot of very poor argillaceous limestone. Winslow's limestone is sometimes locally named the Mount Pleasant bed.

"When Winslow's quarry was visited in 1879, it was producing from 30 to 45 bushels a day, a royalty of one cent a bushel being paid for the privilege. The run of the kiln at that time sold for 10 cents per bushel, being used as a fertilizer. When sold for plaster, it was necessary to pick the lime, and the price obtained for this grade was 14 cents per bushel. The experience of the kiln burner has been that 1 bushel of coal is required for every 6 bushels of lime obtained."

"Above the limestone occurs a lean iron ore, which it would never be profitable to work for the manufacture of iron, as the ore is not sufficiently rich in iron, and is not in sufficient quantity, to make such work profitable."

No specimens of the Vanport limestone collected by the writer in his investigations in Elk County have been analyzed as its importance here did not seem to warrant such expenditure. The following analyses were made by the Second Geological Survey of Pennsylvania:

Analyses of Vanport limestone in Elk County

	1	2	3	4a	4b	4c
$CaCO_3$	86.910	86.214	91.785	27.857	54.553	49.732
$MgCO_3$	6.659	1.785	1.808	.983	1.135	1.331
$Al_2O_3 + Fe_2O_3$	2.205	2.610	1.710	3.830	3.030	3.650
P.	.017	.050	.032	.062	.104	.238
SiO_2	2.390	7.370	3.370	61.670	38.950	41.690

	5a	5b	6
$CaCO_3$	94.357	94.107	85.714
$MgCO_3$	1.634	1.369	1.171
$Al_2O_3 + Fe_2O_3$	1.638	1.626	3.422
P	.031	.063	.069
SiO_2	1.630	2.200	8.390

1. Vanport limestone. G. W. Winshow's farm, two miles northeast from Benezette. Ten feet thick. Rather coarse grained; brittle; mottled with calcite and more or less stained with ferric oxide. Color, generally pearl gray. (2, p. 91)

2. Vanport limestone. One mile east from J. S. Chamberlain's farm, from branch of Toby creek, Fox township. Very fine grained and brittle; fracture, subconchoidal; dark bluish gray. (2, pp 91-92)

3. Vanport limestone. Brandy Camp P. O., Horton township, Elk County. Rather coarse grained; brittle; mottled with calcite; bluish gray. (2, pp. 91-92)

4. Vanport limestone. From Oyster's quarry, Brockport, Horton township. 7 feet more or less, thick. (a) Top stratum, appearance shaly; fossiliferous; comparatively soft; bluish black. (b) Middle stratum fine-grained; brittle, argillaceous; dark blue. (c) Bottom stratum. Appearance shaly; fossiliferous; bluish black. (2, p. 92)

5. Vanport limestone. Gen. Kane's quarry. Jones township; Johnson Run coal basin; four miles northeast from Wilcox. (a) Upper bed. Fine grained and very brittle; more or less stained with iron oxide; reddish gray. (b) Lower bed. Rather fine-grained; brittle, somewhat mottled with calcite; dark-bluish gray. (2 pp. 92-93)

6. Vanport limestone. At Kyler's Corners, Fox township. On east side of Little Toby Creek. Very fine-grained brittle, fracture conchoidal; color, bluish gray. (2, pp. 92-93)

OTHER LIMESTONES

The other limestones of Elk County scarcely deserve mention and have not been investigated by the writer. Ashburner observed limestone in the Pocono formation in Jones and Benezette townships. In the former it was a "massive blue fossiliferous limestone" occurring "about 200 feet below the bottom of the Olean conglomerate."

About one mile west of Benezette, Ashburner (3, pp 247-248) noted three limestones in the Pocono giving the following section and descriptions:

1.	Upper limestone	7′
2.	Gray and olive shale and slate	5′
3.	Gray and greenish-gray hard argillaceous sandstone	60′
4.	Middle limestone	2′
5.	Gray and greenish shales	60′ ±
6.	Lower limestone	2′
		136′ ±

"The upper limestone is fossiliferous; the fragments of the shells, however, are so imperfect that their species could not be determined. It contains slate and shale bands, and iron and clay balls. There is a strong dip of the bed toward the west, at the rate of 3 or 4 feet to the 100 feet. I was informed by Mr. Simon P. Romig, who lived at Benezette in the fall of 1879, when the examination was made, that the limestone from the lower bed was easily burned, and produced a white and brown lime, which was found to be an excellent fertilizer. In 1874 Mr. Romig reported that he had burned 300 bushels of lime from this bed.

The upper and middle of these limestones were analyzed with the following results:

Analyses of Pocono limestones

	1	2
$CaCO_3$	36.785	76.143
$MgCO_3$	1.408	1.740
$Al_2O_3 + Fe_2O_3$	10.070	3.680
P	....	....
SiO_2	50.670	15.980

1. Benezette Upper limestone. On Caledonia road, one mile west from Benezette, Elk County. Pocono. 7 feet thick. Appearance very sandy and coarse grained; fossiliferous; light bluish gray generally; (2, p. 93)

2. Benezette Middle limestone. On Caledonia road, one mile west from Benezette, Elk County. Pocono. 7 feet thick. Appearance rather shaly, very brittle, fossiliferous; dark-bluish gray. (2, p. 93)"

The Lower Freeport limestone was identified in a few isolated localities in Fox and Horton townships. "It is generally composed of a pearl gray, rather fine-grained and brittle stone with a conchoidal fracture." Specimens analyzed by A. S. McCreath gave the following results: (3, p. 235)

Analyses of Lower Freeport limestone

	Chamberlain Farm	McAllister Farm	Fox Farm
$CaCO_3$	81.875	69.357	57.321
$MgCO_3$	7.189	9.308	8.854
$Al_2O_3 + Fe_2O_3$	2.750	4.835	7.940
P	.066	.077	.038
SiO_2	6.540	13.680	21.250

A limestone with a thickness of 4 feet was observed in Horton Township and called the Johnstown Cement bed by Ashburner (3, p. 237) and Upper Freeport Limestone by McCreath (2, p. 91). It analyzed as follows:

$CaCO_3$ 80.357 $MgCO_3$ 1.619 Al_2O_3+Fe_2O_3 3.610 P .086 SiO_2 12.290. It is Freeport Upper limestone from J. S. Hyde's farm, Horton township, one mile south from Brandy Camp P. O., on Brandy Camp creek. It is rather coarse grained and brittle; fracture irregular; light bluish gray. (2, p. 91).

The Johnstown cement bed has been noted in several places in Horton, Fox and Jay townships but it is of no importance. It is thin in almost every place, but ranging from 2 to 6 feet. The following analysis shows its character in one locality: $CaCO_3$ 50.357 $MgCO_3$ 2.467 Al_2O_3+Fe_2O_3 7.040 P .054 SiO_2 36.860 Location J. C. McAllister's farm, Horton Township, Brandy Camp P. O. Appearance sandy; rather coarse-grained; very hard and tough; light bluish gray. (2, pp. 92-93)"

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ERIE COUNTY

Erie County is markedly deficient in limestones and it is doubtful whether any have ever been quarried or mined within the entire county. The rocks which outcrop belong to the Portage, Chemung, and Catskill series of the Devonian Age and the lower part of the Pocono of Mississippian Age. These strata consist almost entirely of shales and sandstones.

The only limestone known positively to outcrop in the county is the Cussewago, a member of the Catskill series. It is between 1 and 2 feet in thickness. It is a compact, grayish-white, siliceous limestone which breaks with a glassy fracture. It is entirely confined to the southeastern corner of the county. It has been described from Concord Township south of Corry but could doubtless be found in other localities in that section. It is probable that stone may be present in this stratum that would make fairly good agricultural lime yet it is improbable that it would pay to produce it.

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FAYETTE COUNTY

Limestones occur at a number of different geological horizons in the strata of Fayette County. The rocks exposed range in age from the Catskill (Devonian) to the Dunkard (Permian) and each group, with the exception of the Catskill, contains one or more limestones. Outcrops of limestones are widespread so that the farmers of almost every community were able readily to obtain limestone to burn for agricultural use when the custom of liming the soils was more common than at present. In the main, the limestones of Fayette County are impure and interbedded with much shaly material so that they could not well serve as a basis for any extensive quarrying industry. Locally, however, they have been quarried in scores of places for the manufacture of agricultural lime and for road metal. The Loyalhanna siliceous limestone, which might perhaps better be designated as a calcareous sandstone, is the only one in the county which has been worked on any considerable scale in recent years.

Generalized geologic section of Fayette County

	Feet
Carboniferous	
Permian (Dunkard)	
Washington group	400+
Upper Washington limestone	
Middle Washington limestone	
Lower Washington limestone	
Washington coal	
Colvin Run limestone	
Waynesburg "A" coal	
Mount Morris limestone	
Waynesburg sandstone	
Pennsylvanian	
Monongahela group	375
Waynesburg coal	
Waynesburg limestone	
Uniontown coal	
Uniontown limestone	
Benwood (Great) limestone	
Sewickley coal	
Fishpot (Sewickley) limestone	
Redstone coal	
Redstone limestone	
Pittsburgh sandstone	
Pittsburgh coal	
Conemaugh group	600
Pittsburgh limestones	
Connellsville sandstone	
Clarksburg limestones	
Morgantown sandstone	
Barton coal	
Barton limestone	
Ames (Crinoidal) limestone	
Saltsburg sandstone	
Bakerstown (Hager) coal	
Pine Creek limestone	
Farmington coal	
Brush Creek limestone	
Brush Creek coal	
Mahoning sandstone	
Allegheny group	275
Upper Freeport coal	
Upper Freeport limestone	
Bolivar fireclay	
Lower Freeport coal	
Lower Freeport limestone	
Upper Kittanning coal	
Johnstown (Cement) (Upper Kittanning) limestone	
Middle Kittanning coal	
Lower Kittanning coal	
Clarion coal	
Brookville coal	
Pottsville series	180±
Homewood sandstone	
Mercer coal group	
Connoquenessing sandstone	
Mississippian	
Mauch Chunk series	250
Greenbrier (Mountain) limestone	
Loyalhanna (Siliceous) limestone	
Pocono series	400+
Devonian	
Catskill group	400+

In the section only the members of economic importance or of special prominence are given. The greater portion of the stratigraphic

column consists of unnamed shales and sandstones. Occasional lenses of limestone, some of which in restricted areas may be of some importance, are likewise omitted in the section.

Distribution of the Geological Formations. The oldest rocks of Fayette County, the Catskill, Pocono and Mauch Chunk, are entirely confined to the two prominent ridges, Chestnut Ridge and Laurel Hill, that extend through the eastern half of the county from the West Virginia line to Indiana County. The Pottsville sandstones are developed along the lower slopes of these ridges. The Allegheny and Conemaugh groups form most of the surface strata throughout the Ligonier Valley and outcrop over considerable areas in the western half of the county. The Monongahela and Washington groups are in the western part.

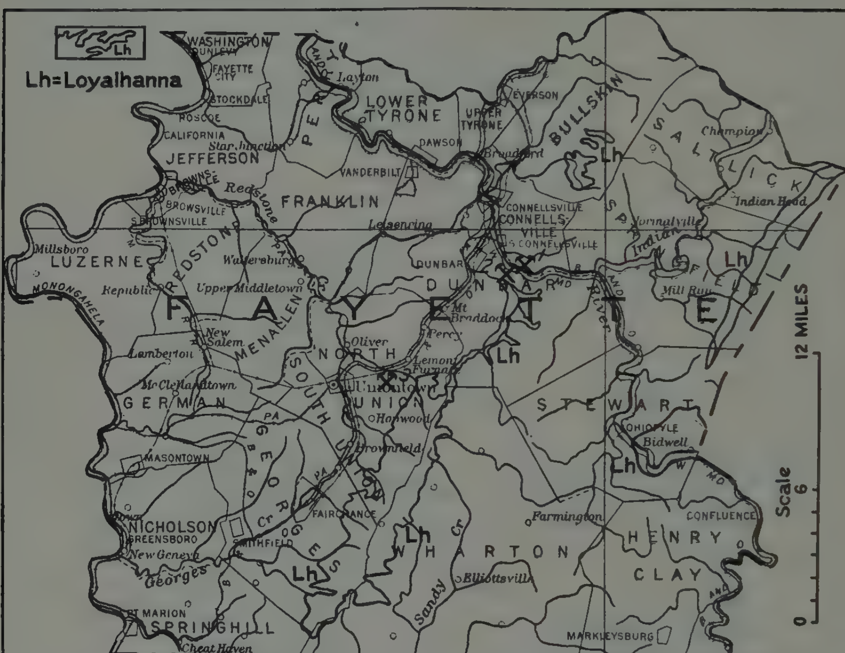

Fig. 13. Limestone areas in Fayette County.

1. Youghiogheny Crushed Stone Co., Connellsville Bluestone Co. 2. New Castle Lime and Stone Co. 3. Coolspring Bluestone Quarry Co.

LOYALHANNA LIMESTONE

The Pocono series consists mainly of sandstone and just above it is a formation thhat was long known as the Siliceous limestone but in recent years has been given the name of Loyalhanna. It consists of grains of quartz sand cemented by calcium carbonate and grades downward into a true sandstone in which the cementing material is siliceous. It is normally gray in color but in places slightly reddish or brownish. Locally it contains some pyrite and in such localities the exposed weathered surfaces are distinctly discolored due to the oxidation of the pyrite. The most distinctive feature in most places is the prominent cross-bedding. Most of the beds are fine grained and so uniform

in texture that they can easily be split and broken into regular pieces. This is one reason why it has been practicable to use this stone for paving blocks. The stone is hard and much of it, especially the finer grade, has been accepted by the State Highway Department for road construction. The greater portion, however, has been utilized for railroad ballast. Many years ago some of it was burned for lime. The common report is that it produced a very white lime and that the quartz sand grains which were unaltered in the burning process were present in sufficient quantity to make a fair quality of mortar without the addition of other sand. In some cases it is feared that the amount of lime produced might be insufficient to form a mortar.

The Loyalhanna is 62 feet thick along Youghiogheny River. It thins toward the southwest and is reported by Stevenson to be "barely 4 feet where last seen within the State." (3 p. 53)

Although the Loyalhanna limestone seems to be continuous throughout Fayette County and should be exposed generally on both slopes of Laurel Hill and Chestnut Ridge, actually it can seldom be located except along the stream courses on account of the great accumulation of hillside debris. In recent years it has been worked only at three places which will be described first.

The largest operation is that of the Youghiogheny Crushed Stone Co., formerly the Casparis Stone Co., and afterwards the Vang Construction Co. It is located about 3 miles southeast of Connellsville on the north side of the gorge cut by Youghiogheny River as it crosses the Chestnut Ridge anticline. The quarry is about 500 feet or more above the river. The shipping point on the Baltimore & Ohio Railroad below the quarry is known as Casparis Station.

A quarry has been in operation at this point for a number of years. The working face is about 1000 feet long and a great quantity of stone has been removed. For several years past no open cut quarrying has been done as the overburden became too heavy with the extension of the operations into the hill. The stone is now obtained entirely by mining. Three drifts have been driven into the face of the old quarry. In 1929 when the locality was visited these had extended about 500 feet. The openings are 40 feet wide and 40 foot pillars are left. The deposit is 62 feet thick, but only 45 to 50 feet of the stone is removed as it is advisable to leave considerable of the massive stone for a roof. The mine is advanced by driving a tunnel 7 feet high and 8 feet wide about 10 feet from the top. The balance is shot down in 2 or 3 levels, loaded into cars by steam shovel and hauled to the crusher. Three sizes were being prepared, 3/7 to ⅝ inches, 4/8 to 1¼ inches, and 1¼ to 2¾ inches. Only crushed stone is produced. During certain seasons the bulk is used for highway construction but in other years most of the product is used for railroad ballast. The operation is closed for about 3½ months during the winter. The capacity has been 150,000 tons per year but this will be greatly increased shortly according to a report. Improvements to cost $175,000 will be made consisting of a "road surfacing plant with a capacity of 1200 tons daily and facilities for increasing the ballast output to 40,000 tons monthly."

The beds are extremely massive and greatly crossbedded although not to quite such a degree as in some other places. Part of the stone is bluish gray and the other gray. Some small pellets of pyrite about the size of a pea were observed in a few places in the gray stone. On weathering these stain the stone nearbv to a rusty brown. On weath-

ered surfaces this ferruginous discoloration is marked. A few vertical cracks have permitted the surface waters to pass downward and to dissolve some of the cementing calcium carbonate, leaving loose or only slightly coherent sand. These are called sand streaks. Some of these are 4 inches wide. In a few places clay has filled these cracks, brought there by the surface waters from above. In part of the operation there is a gentle westerly dip of the strata but in other parts they are practically flat.

Another similar operation nearby is that of the Connellsville Bluestone Co., which however has a much smaller production.

The New Castle Lime and Stone Co. is working the Loyalhanna limestone along the north side of Dunbar Creek about 2 miles east of Dunbar. This is known as the Dunbar Bluestone Plant. The company, has a quarry face about 2000 feet long and in addition has driven three tunnels into the hill at the part of the quarry where the overburden had become excessive. The Loyalhanna is at this point 55 to 60 feet thick and is overlain by 40 feet of shale and sandstone and above that is 40 feet of Greenbrier limestone and shale. In mining the upper portion is left as a roof so that only 47 to 50 feet of stone is obtained. The entries are 30 feet wide with 40 foot pillars. The tunnels have only been driven about 100 feet.

''The tunnels are advanced by cutting a slice at the top of sufficient height for the miners to work conveniently, and of the width of the tunnel. This constitutes a removal of the top key and permits convenient barring down from the roof of any loose rock. When this preliminary cut has advanced 15 to 25 feet the bottom of the cut is drilled and shot, making a second bench.'' The top slice is about 7 feet, the second cut about 17 feet, and the third is 22 feet, or 46 feet altogether.

''At present the stone for paving block is taken from the open quarry in large blocks, which are drilled and split to the approximate size of the finished block and hand-trimmed to the correct size. Black powder is used for splitting the larger stone; and no dynamite is used in this part of the quarry, as it shatters the stone excessively.

''Blocks are made by the men on a contract price of 4c each, the trimming of the stone being a trade in itself. An average production per man of 200 blocks daily is maintained with several trimmers having made as high as 600 blocks in 8 hours. The blocks are so made that 23 of them will cover one square yard of street surface.

''About 100 men are kept employed by the company, 26 being used for production of crushed stone and the balance in the paving block production.'' (10, pp. 42-43)

The strata are only gently inclined. One measurement showed a strike of N5°W with a dip of 7°SW. In practically every respect the stone from this quarry is similar to that of the Youghiogheny Crushed Stone Co.

The product of the Dunbar quarry is crushed stone for highway construction and railroad ballast, and paving blocks. In 1929 the stone from the open quarry was being manufactured into paving blocks, with 80 men employed in splitting and dressing the stone and the stone from the mine tunnels was being utilized as crushed stone. The refuse from the manufacture of blocks is also crushed. The operation is well equipped throughout. The annual production is given as 200,000 tons of crushed stone and about 900,000 paving blocks.

In April 1929 the Coolspring Bluestone Quarry Co. started to reopen an old quarry in the Loyalhanna limestone about 2 miles east of Coolspring or about 5 miles east of Uniontown. The quarry had been idle for about 20 years. The stone is similar to that in the operations just described. The stone has very little overburden at the point where the quarry has been opened. Some crushed stone had been sold and some paving blocks made at the time the operation was visited, but the plant was in process of equipment so the output was small. The conditions appear favorable for the development of a large operation if the market conditions justify the enlargement.

Some of the other places where the Loyalhanna is known definitely to be present are now cited but it must not be assumed that in other places on the slopes of Chestnut Ridge and Laurel Hill it is not present. In Henry Clay Township it is reported as being well exposed on the main fork of Beaver Creek, west side of Laurel Hill. In Wharton Township it is exposed along Chaney Run near Wharton Furnace on the east slope of Chestnut Ridge. Two quarries near the National Pike were once opened to obtain stone for the repair of the roadbed. One of these localities, about 1½ miles north of the Pike, was visited in 1921 by the writer. The Loyalhanna appears to be about 40 feet thick and to contain some good stone which might be readily quarried. A poor road leads to the place. Where the Youghiogheny River cuts through Laurel Hill it is exposed about 1½ miles above Ohiopyle and also on the upper slope of Sugarloaf Mountain nearby in Stewart Township. In Springfield Township it has been reported to be exposed in the headwaters of Mill Run on the west slope of Laurel Hill and on the eastern side of Chestnut Ridge in the Youghiogheny River gorge a short distance below the mouth of Indian Creek. At the latter place it was quarried for some time prior to 1878 to obtain paving blocks for Pittsburgh streets.

The quantity of Loyalhanna limestone that is available in Fayette County is exceedingly great. The present operations can be greatly extended and other advantageously situated locations could doubtless be found if the demand for the stone should be increased.

Dulany Cave on Chestnut Ridge east of Fairchance is in this limestone. The explored part of the cave is 2000 feet long, and descends 300 feet below the entrance and outcrop down the dip.

Chemical analyses of Loyalhanna limestone of Fayette County

[Pittsburgh Testing Laboratory, analyst]

After drying at 105°C:

	1	2	3
SiO_2	53.60	51.32	43.86
Al_2O_3	3.17	2.92	2.13
Fe_2O_3	2.29	.72	1.57
TiO_2	.20	.30	.20
CaO	22.00	24.70	27.74
MgO	.94	.58	.58
SO_3	trace	trace	1.76
Loss on ignition	17.58	19.00	22.16

1. Quarry of Youghiogheny Crushed Stone Co.,—composite sample.
2. Dunbar plant of New Castle Lime and Stone Co.,—composite sample.
3. Quarry of Coolspring Bluestone Quarry Co.,—composite sample.

The analyses above show a fairly uniform product and agree in general with an analysis of the same stone from Westmoreland County. As discussed in an earlier chapter on "Uses of Limestone," it is believed that stone of this kind might well be utilized in the manufacture of mineral wool.

GREENBRIER LIMESTONE

The Mauch Chunk series in Fayette County contains the Greenbrier (Mountain) limestone, one of the most valuable limestones of the county. It lies from 40 to 50 feet above the Loyalhanna limestone and outcrops on both sides of Laurel Hill and Chestnut Ridge. As in the case of the Loyalhanna, it is difficult to find the outcrop in many places on account of the great mass of loose rock that covers the slopes of these two steep mountains.

The Greenbrier limestone consists of a series of extremely fossiliferous limestones interbedded with greenish to reddish fossiliferous shales and argillaceous limestones. Some beds consist of very fine limestone, suitable for the production of a high grade lime, and other layers are entirely too shaly to be of value. The better beds contain stone hard enough for use on the highways, and have been quarried for that purpose.

Years ago the Greenbrier was quarried in many places to supply stone for small agricultural lime operations. With local lime burning much less common there has been little quarrying of this limestone in recent years. It varies greatly in thickness but in general is rather thin in the north part of the county where it appears to be less than 10 feet thick in places and increases toward the southwest. It is about 40 feet thick in some places in the southern part of Fayette County and very much thicker in West Virginia where it has been separated into several distinct divisions.

In Henry Clay Township it has been reported as imperfectly exposed on the west side of Laurel Hill. In Wharton Township it is well developed on the east side of Chestnut Ridge and has been quarried in several places for lime, fluxing stone, and crushed stone for the roads. It was once quarried on Chaney Run about a mile from Wharton Furnace. Stevenson (3, p. 69) described the occurrence as follows:

"Only the middle and lower beds are now exposed, and they are separated by about 40 feet of shale. The upper of these is 20 feet thick, compact and loaded with fossils. The specimens in the harder portions are crushed, but those from the argillaceous portions are in excellent condition. This was quarried to supply the furnace. The other bed is 8 feet thick, blue, free from clays, contains many fossils, and yields a beautifully white lime."

Other iron furnaces in Wharton Township obtained their fluxing stone from the Greenbrier limestone.

At the Thompson quarry along the National Pike about 6½ miles southeast of Uniontown, where the State Highway Department has in

recent years obtained much material for roads and which was previously worked for agricultural lime, the following typical section is exposed:

Section of Greenbrier limestone 6½ miles southeast of Uniontown

	Ft.	in.
Surface clay passing downward into green shale	3	6
Massive bed of hard limestone	1	8
Greenish, fossiliferous shale with thin streaks of limestone	2	0
Thick-bedded limestone	4	0
Dark-colored shale	1	6
Thick-bedded limestone	22	0
Argillaceous limestone	0	6

About 1 mile north of this locality along Beaver Creek two quarries have been worked recently to obtain material for small kilns. The beds are lithologically similar to those given in the above section but with material differences in thickness which seems to indicate considerable variation in the formation.

The Greenbrier is exposed near the top of Sugarloaf Mountain in Stewart Township and is developed in the headwaters of Mill Run along the west slope of Laurel Hill in Springfield Township. It is also exposed along the Youghiogheny gorge through Chestnut Ridge in the same township.

It is poorly exposed in the gap cut by Youghiogheny River through Chestnut Ridge. A 10-foot thickness has been reported but it is probably thicker if one includes the interbedded shales.

In Dunbar Township it is exposed along Dunbar Creek. At the Dunbar quarry of the New Castle Lime and Stone Co. it is exposed in the hill above the quarry where it consists of about 40 feet of limestone and interbedded shale.

Near Hopwood in North Union Township it "was formerly quarried for use on the road, and the exposure seems to indicate a thickness of not far from 40 feet. The upper portion is light blue and contains many fossils replaced by calcspar; the middle is dull blue, somewhat clayey, and contains many fossils, though the species are few. Below this is a rude mass of clay, shale and argillaceous sandstone, separating it from the bottom portion, which is extremely sandy, and is known here as "whinstone." It burns well enough, but is so sandy that the lime makes a fair mortar without the addition of sand." (2, p. 165)

The Greenbrier is exposed in a few places along the west slope of Chestnut Ridge east and southeast of Uniontown in South Union Township. A small quarry has recently been worked along the National Pike.

In Georges Township the Greenbrier is exposed and was formerly quarried near the headwaters of several small streams east of Haydentown. The upper layers are said to have yielded a fine grade of white lime but the lower layers were more sandy, yet they too produced a satisfactory product for building purposes.

LIMESTONES OF THE ALLEGHENY GROUP

Johnstown (Cement) limestone. The Johnstown limestone has been noted in the Ligonier Valley of Fayette and Westmoreland coun-

ties. In Fayette County it appears to be mainly if not entirely confined to Springfield and Salt Lick townships. Stevenson (3, pp. 38-39) gives the following description: "The most southern locality in which the bed was seen is on Laurel Run in Springfield township of Fayette. There, at somewhat more than a mile above Fayette furnace, it is not far from 8 feet thick, but at the furnace it is wanting and in its stead there is a brownish ferriferous shale. The shale prevails at this horizon everywhere in the vicinity except for a little distance along Indian Creek near Springfield (Normalville) where the limestone again appears." It is reported to have once been quarried for agricultural lime at the latter place.

Lower Freeport limestone. In few places in Fayette County has the Lower Freeport limestone been recognized and where seen it is only 2 to 2½ feet thick and of poor quality. The best exposures seem to be those along Dunbar Creek and Youghiogheny River where they cut through Chestnut Ridge.

Upper Freeport limestone. In Fayette County the Upper Freeport limestone is of less importance than in some of the counties to the north and northwest. It is the only important limestone member of the Allegheny formation of Fayette County. The formation is exposed on both sides of Chestnut Ridge and Laurel Hill. Most of the exposures of this limestone are on the sides of Ligonier Valley. It lies from 5 to 15 feet below the Upper Freeport coal and has a maximum thickness of about 18 feet. In some places it is entirely absent and in other sections only a few feet thick. In Henry Clay Township, this limestone outcrops on both sides of Laurel Hill. In Wharton Township it is more than 10 feet thick on Big Sandy Creek near the State line, but absent along the National Pike. It is 6 feet thick along the headwaters of Big Meadow Run. It is well developed in Stewart Township both in the western part and along Jonathan and Cucumber runs. It is 18 feet thick on the hill above the mouth of Jonathan Run but only 3 feet thick at the northern edge of the township. It is irregular in the region north of Youghiogheny River. Near Ohiopyle it is 9 feet thick, near Normalville from 3 to 5 feet thick, and in some places probably absent. North of Normalville it seems to be persistent to the Westmoreland County line.

Stevenson (3, pp. 33-34) gives the following description of this limestone:

"This rock varies quite as much in quality as it does in thickness. At most localities it has on top a thin layer of dark blue impure slaty limestone, which is worthless, while the remaining portion is dull bluish gray with irregular fracture and more or less argillaceous. When burned hastily, it is apt to fuse, but if burned slowly it yields a lime, which does well for agricultural purposes, for which use it is highly valued. Oftentimes it is quite ferruginous at the outcrop and it was mined as an iron ore at Laurel Hill furnace. At some localities in Fayette it has been mistaken for iron ore and at the head of Jacob's creek a lean ore is associated with it."

The Upper Freeport limestone was quarried on a small scale for agricultural lime many years ago in a number of places throughout the county but in recent years has been little used.

LIMESTONES OF THE CONEMAUGH GROUP

In the geological section given on a previous page the Conemaugh is shown to contain the *Brush Creek, Pine Creek, Ames, Barton, Clarksburg,* and *Pittsburgh* limestones. At one place or another, each of these may be found although no one is persistent throughout the county. In general, these limestones are thin, mostly from 1 to 2 feet thick, and impure, due to high argillaceous and ferruginous content. Some of them have been utilized to a very small extent.

The Ames has been more frequently reported than any of the others. It has been recognized in Wharton, Springfield, North Union, Dunbar, Menallen, and Perry townships. It is an impure highly fossiliferous, greenish-gray limestone, with a maximum thickness of about 4 feet.

An analysis of the Pittsburgh limestone from the Lemont Furnace quarry 3 miles northeast of Uniontown is as follows: (4, p. 290)

Analysis of Pittsburgh limestone from Lemont Furnace Quarry

$CaCO_3$	87.868
$FeCO_3$	1.914
Al_2O_3	.135
$MgCO_3$	1.733
SiO_2	7.360
S	.106
P	.050

LIMESTONES OF THE MONONGAHELA GROUP

Redstone limestone. Beneath the Redstone coal bed is the Redstone limestone that is well developed in the northern part of Fayette County between Redstone Branch and Youghiogheny River where it was once quarried for flux for the local iron furnaces. Elsewhere it has rarely been noted. It is 10 to 20 feet thick in a few localities. It has been reported particularly near Lemont Furnace in North Union Township, where it was once quarried; near Ferguson in Dunbar, where it is 10 feet thick and was quarried for flux; and on Browneller Run in Perry Township, where it is 8 feet thick and was burned for agricultural lime. It is a fairly pure limestone in most localities, but in some places is highly ferruginous.

Analysis of Redstone limestone

$CaCO_3$	66.471
$MgCO_3$	17.711
Al_2O_3	.812
$FeCO_3$	5.178
S	.080
P	.048
Insoluble	9.460

Sample from Lemont Furnace quarry, 3 miles northeast from Uniontown, Fayette County. Hard and brittle; sparkles with calcite; pearl gray, with conchoidal fracture. (4, p. 289).

Fishpot (Sewickley) limestone. Between the Redstone and Sewickley coal beds there are limestones, sandstones, and shales. About midway between the two coals is the Fishpot or Sewickley limestone. It is variable in thickness and characteristics. In places it is absent and elsewhere may be as much as 35 feet thick. It ranges from limestone of such impurity as to be worthless to fairly pure massively-bedded stone well suited for both lime and flux. It has been observed in various places in the county.

The Fishpot lying about 2 feet below the Sewickley coal is present about one mile north of Point Marion, Springhill Township. It is 5 feet thick and ferruginous where seen 2½ miles northwest of Smithfield. It is developed about Uniontown. It was quarried for flux for the Lemont Furnace in North Union Township. Near Ferguson, Dunbar Township, it is 2 feet thick and was once quarried for flux. On Browneller Run in Perry Township it is 10 feet thick. Along Redstone Creek and Monongahela River in Jefferson Township it is 30 feet thick. Along Redstone Creek near Tippecanoe in Franklin Township it is 25 feet thick and of good quality. On the hillside of Dunlap Creek in Brownsville Township it is 35 feet thick. "At the base for about 10 feet, it is quite ferruginous, but the rest of the bed is very clean and yields a lime of excellent quality." (2, p. 233). It has here been quarried for lime burning. In Luzerne Township opposite Fredericktown it is 30 feet thick. In Nicholson Township it is 10 feet thick at New Geneva. It is generally too ferruginous to be of any value.

Analysis of Fishpot limestone, Fayette County

$CaCO_3$	80.647
$MgCO_3$	2.217
$FeCO_3$	1.657
Al_2O_3	.543
SiO_2	10.770
FeS_2	1.125
H_2SO_4	.052
P_2O_5	.066
H_2O	1.010
Carbonaceous matter	1.250

Sewickley (Fishpot) limestone, Oliphant Furnace quarry, Georges Township, Fayette County. (4, p. 287)

Benwood (Great) limestone. The Benwood limestone is the most prominent and persistent member of the Monongahela group in the region. It is as much as 85 feet thick in some sections although about half may consist of interbedded shales. Individual beds may be as much as 2 feet thick. No generalization can be made regarding its adaptability on account of its variable character. In one locality certain beds are sufficiently pure to be desirable for lime or flux whereas elsewhere the stone contains large quantities of siliceous and argillaceous matter. It has been extensively used in the production of agricultural lime for local consumption. Some of it is entirely satisfactory for road metal although much of it is too shaly.

This limestone member is present in almost every region where the Monongahela group appears, which is mainly in the western part of Fayette County.

The Benwood is extensively developed in most of that part of the county lying west of Chestnut Ridge and has been quarried for limestone, flux and road metal. It is not a single bed or series of beds of limestone, but instead a series of limestone and shale strata and their gradations from limestone to shale. Some layers are fairly pure and others decidedly otherwise. A few locality descriptions are given but these are by no means all of the places where it is exposed. Near Chadville, Georges Township, about 10 feet of limestone appears but this is only part of the series. In various places about Uniontown it is well developed. It was once quarried for flux near

Lemont Furnace but was too siliceous to be of much value. Stevenson (2, pp. 178-179) gives the following section of Benwood limestone:

"Section of Benwood limestone between Mount Braddock and Starnbaugh

		Feet
1.	Reddish shale	6
2.	Limestone	15
3.	Dark shale, with thin sandstone	10
4.	Limestone	8
5.	Clay	1
6.	Limestone	16
7.	Shale	10
		66

"No. 2 is quite siliceous and some of the layers are conglomerate. No. 4 is in several layers, varies from blue to red and is more or less argillaceous throughout. All of its layers contain fossils, which are very minute and are replaced by calcspar, so that the freshly fractured surface has a birdseye appearance. No. 6 is a variable mass, some of the layers being pure enough for use as flux in the furnace, while others are almost a compact calcareous clay. The upper portion for about 6 feet is evidently a cement rock. At one time the Sewickley coal bed was mined near this cut."

Near Ferguson, Dunbar Township, the Benwood is 55 feet thick and is mainly argillaceous but some was quarried for flux. On Browneller Run in Perry Township it is 55 feet thick; the individual beds are gray to dove-colored, fairly brittle and decompose readily when exposed to the weather. It is developed along Downer's Run in Washington Township. Along Monongahela River in Jefferson Township the Benwood is about 90 feet thick. Along Redstone Creek near Tippecanoe in Franklin Township it consists of a 20-foot upper limestone and interbedded shale beds and a similar 35-foot lower series, the two separated by about 20 feet of sandstone. The lower series was once tested to determine its value in the manufacture of natural cement. It was said to have been found satisfactory. It is developed along the National Pike in Redstone Township and in the bluffs of Monongahela River across from Fredericktown in Luzerne Township where it is about 60 feet thick.

Uniontown limestone. The Uniontown limestone was formerly regarded as the upper portion of the Benwood but is now separated as a distinct member, although in certain places the exact correlation is difficult. It is similar to the Benwood in its general characteristics and composition. In the vicinity of Uniontown it is a massively-bedded limestone in two layers aggregating 10 feet in thickness. Elsewhere it is somewhat thinner. It is well developed in Georges, North Union, South Union, Dunbar, German, Luzerne, Redstone, Menallen, Franklin, Jefferson, Washington, and Perry townships. Near Uniontown it was formerly quarried for the manufacture of cement that was used in the construction of locks on Monongahela River. It has been used for flux, for the manufacture of agricultural lime, and for road metal.

Waynesburg limestone. About 20 feet below the Waynesburg coal is the Waynesburg limestone. It is best developed in German, Red-

stone, and Franklin townships, but also is present in North and South Union, Washington, Jefferson, Menallen, Brownsville, and Luzerne townships. It ranges in thickness from 8 to 35 feet. It produces a fairly good lime.

The Waynesburg is similar in character and composition to the Uniontown and Benwood limestones. Locally it has been quarried but always on a small scale.

LIMESTONES OF THE WASHINGTON GROUP

The Washington group is exposed on the tops of many hills in German, Luzerne, Redstone, Jefferson, Perry, North Union, and Dunbar townships, but contains very few limestones and they are thin and not persistent. The several limestones of this group that are so prominent in Greene and Washington counties have practically disappeared and shales are found at those horizons. In a few places in Redstone and German townships, particularly southeast of Merrittstown, some thin limestones supposed to be the Lower and Upper Washington members have been noted.

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Rock Products

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FOREST COUNTY

No limestones of any importance are known to be present in Forest County. It is possible that the Vanport may be developed in some places in the southeastern part of the county, although thus far it has not been recognized. The Second Geological Survey of Pennsylvania published the following analysis and description of a sandy limestone (2, p. 90).

Analysis of Tionesta limestone

$CaCO_3$	40.642
$MgCO_3$	1.172
$Al_2O_3 + Fe_2O_3$	2.120
P	.018
SiO_2	55.160

Tionesta limestone. Kelley's quarry, four miles east from Tionesta, on Tionesta creek, Forest County. Saddle Bags tract. Two to three feet thick. Coarse grained; appearance, sandy; exceedingly hard and tough; bluish gray.

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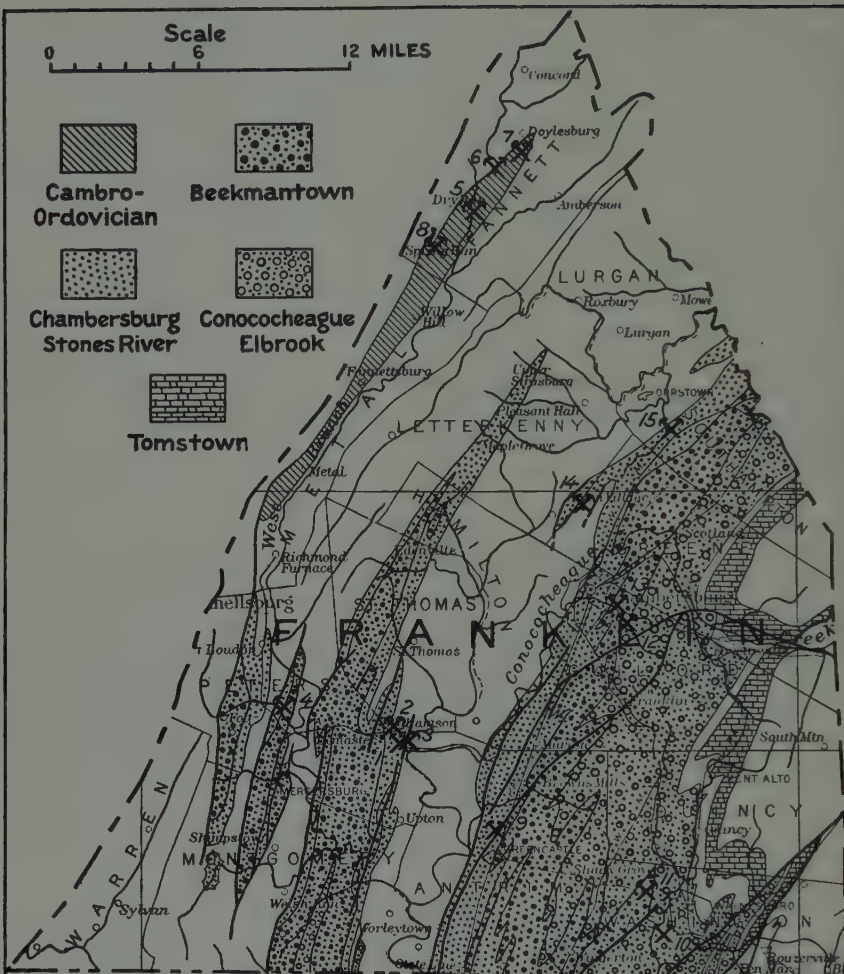

Fig. 14. Limestone areas in Franklin County.

1. J. E. Baker Co.
2. Harry T. Goetz
3. G. M. Dietrich
4. George A. Diehl, Harry T. Goetz
5. Martin F. Hammond
6. Walker Brothers
7. A. E. Doyle
8. D. Frank Crouse
9. William A. Diehl
10. Hess Lime and Stone Co.
11. J. A. Wishard
12. Chambersburg Stone Co.
13. J. S. Brumbaugh
14. Aaron Ebersole
15. Z. S. Brenize

FRANKLIN COUNTY

Franklin County is abundantly supplied with limestones, in fact limestone constitutes the surface rock of almost one-half of the county. South Mountain in the eastern part of the county is composed of pre-Cambrian crystalline rocks and the mountain ridges in the western part are mainly composed of Silurian sandstones. The remainder of the county lies lower and is underlain by more easily erodible rocks consisting of limestone and shale. These are mainly confined to the Great or Appalachian Valley in this region is known as the Cumberland Valley. Between South Mountain and a line passing just west of Chambersburg and Greencastle scarcely any rocks other than limestone and dolomite are present. West of this line to the foot of the mountain ridges, limestone and shale alternate. An isolated band of limestone occupies part of Path Valley lying between Knob and Rising mountains on the east and Tuscarora Mountain on the west, and another double band of limestones occupies part of The Cove lying between Cove and Tuscarora mountains in the southwestern part of the county.

All of the limestones of Franklin County belong to the Cambro-Ordovician with the exception of those in The Cove which are of Helderberg age.

The limestones have not been extensively quarried except in a very few places but small quarries for local use have been opened in scores of places. Except the quarries at Williamson, few have been worked for stone to be shipped out of the county.

The early uses of these limestones were for the manufacture of agricultural lime, as flux in the numerous iron blast furnaces that were located in the region when the local iron ore mines were in operation, and for the construction of buildings. Although they were fairly satisfactory for all of these purposes, in only a few places within the region is limestone being quarried now for any of these purposes.

In recent years the chief use for limestone quarried here has been as ballast in the improvement of highways and also as crushed rock in other construction.

. Throughout the county the soil cover is considerably thinner than in most of the other limestone areas of the State, and, as a consequence, outcrops are more numerous.

CAMBRO-ORDOVICIAN LIMESTONES

The Cambro-Ordovician limestones of Franklin County have an aggregate thickness of about 10,000 feet and have been subdivided into 7 different formations by George W. Stose in the Mercersburg-Chambersburg Folio.[5] These are as follows:*

Ordovician

Chambersburg limestone group. 100-750 feet thick.

Thin-bedded tough dark limestone, usually very fossiliferous with irregular clayey partings giving rise to limestone 'cobble' on weathering. Interbedded shale at the top in most places forms gradation into Martinsburg.

*This column has been arranged to follow the official section of the Pennsylvania Geological Survey although the author prefers the U. S. Geological Survey section which does not include the Canadian.

Canadian

Stones River limestone group. 675-1050 feet.

Very pure, thin-bedded, even-grained, dove-colored limestone at top and bottom with some magnesian layers; granocrystalline gray fossiliferous limestone with thin layer of black blocky chert in middle.

Beekmantown limestone series. 2300 feet.

Thick-bedded, rather pure limestone in large part finely laminated, interbedded with magnesian beds and fine-grained pink to white marble; contains beds of oolite, fine conglomerate, chert nodules, and quartz geodes at several horizons and grading downward into blue limestone with hard siliceous laminae, coarse 'edgewise' conglomerate, and purer fine-grained marble.

Small rosette and 'cauliflower' cherts at or near the top of the formation.

Conococheague limestone group. 1635 feet.

Thin-bedded blue limestone finely banded by thin, hard siliceous, generally contorted laminae that weather in relief and finally disintegrate to slaty sandstone and shale fragments.

Edgewise conglomerate, chert, oolite, and limestone conglomerate containing quartz grains and weathering to porous sandstone at the base.

Cambrian

Elbrook group. 3000 feet.

Gray to pale-blue shaly limestone and calcareous papery shale with some heavier limestone beds at the base and thick-bedded siliceous limestone in the middle.

Waynesboro group. 1000± feet.

Slabby gray calcareous sandstones or sandy limestones and hard slaty purple shale, with limestone and fine-grained white marble in middle. Large scoriaceous white chert heads and vein quartz in lower portion.

Tomstown group. 1000 feet.

Massive and thin-bedded limestone, in part cherty and magnesian, with considerable shale and soft white clay at the base.

About two-thirds of the county is included within the Mercersburg and Chambersburg quadrangles. The distribution of the various formations is shown on the geologic maps of that folio. A considerable portion of the descriptions following are quoted from that source.

The Cambro-Ordovician limestones contain stone suitable for practically every purpose for which limestones are used. They present a wide variety of materials both in physical character and chemical composition. The following descriptions furnish general information but it is well to state that any one contemplating the use of the limestones for any purpose other than for crushed stone or agricultural lime, for which practically any within the county are satisfactory, should make careful investigations on account of the numerous folds and faults that result in rather complicated structures.

"Lime is extensively used in this area (5, p. 18) for enriching the soil, and the various limestones are quarried for this purpose throughout both quadrangles. Much of the limestone, especially that of the Conococheague and lower formations, is very impure, usually containing a large percentage of magnesium carbonate and fine siliceous and argillaceous matter, but beds can be found almost anywhere that will yield lime suitable for local use as fertilizer. Lime is especially beneficial to the sandstone and shale soils, and kilns are consequently more numerous along the shale border. Much of the lime is burned in heaps in the field without permanent kilns. Only those quarries that are large and have more than a local trade are shown on the geologic maps.

The Stones River limestone is the purest of the Shenandoah group and all the high-grade lime is made from it.

"A sample from the Stones River limestone near Mercersburg showed an analysis 96.4 per cent of calcium carbonate. Although these pure beds are not so thick as those at Martinsburg, W. Va., where the rock is quarried on an enormous scale for shipment as flux to the iron furnaces of Pittsburgh, the analyses compare favorably. Three samples of Stones River limestone from the Martinsburg quarries contain 96.2, 97.7, and 98.1 per cent of calcium carbonate.

"The outcrop of the Stones River formation is shown on the areal geology maps (of the U. S. G. S. Geologic Folio No. 170), and rock suitable for lime production can be obtained at most places within its area. Numerous quarries are located in the belts between Chambersburg and Greencastle adjacent to the shale lands, and a large industry has been developed in the Rocky Spring cove, which is surrounded by shale farm lands. The Stones River limestone is exceptionally pure and thick bedded in this locality and the large quarry 1 mile north of Beautiful runs six kilns.

"Certain beds in the Chambersburg and Beekmantown formations are also fairly pure and make a lime of good grade. Large quarries and kilns in the Beekmantown are located at Stonehenge and Stoufferstown, east of Chambersburg. Exceptionally pure beds in the Chambersburg limestone occur at Fort Loudon and in the vicinity of Blue Spring, southwest of Mercersburg. A sample from the Chambersburg limestone near Mercersburg showed on analysis 93.2 per cent of calcium carbonate and only 0.07 per cent of magnesium carbonate, the rest being largely insoluble impurities.

"A large number of beds in the Shenandoah group, especially in portions of the Tomstown and Beekmantown limestones, contain a high percentage of magnesium carbonate. Beds ranging from 25 to 40 per cent in magnesium carbonate alternate with almost pure limestone containing 1.4 to 3 per cent, but by selection in quarrying the highly magnesium layers can be segregated."

"Certain black limestones in the transition beds at the base of the Martinsburg formation are probably suitable for the manufacture of natural cement. These beds are generally too thin and too much mixed with shale to be economically used for this purpose, but they thicken toward the west, and beyond Mercersburg, especially in the eastern part of McConnellsburg Cove, individual beds are 1 foot thick and the more massive portion aggregates 6 to 8 feet in thickness. An analysis of a sample of rock from this horizon in the Rocky Spring Cove is as follows:

Analysis of black limestone at base of Martinsburg formation in Rocky Spring Cove

[W. T. Schaller, analyst]

$CaCO_3$	68.82
$MgCO_3$	.20
$FeCO_3$	1.34
Fe_2O_3	.55
Al_2O_3	2.82
SiO_2 etc. (insoluble)	22.93
	96.66

"This rock differs from the best natural cements in its low percentage of $MgCO_3$, which may vary in the different beds, and the use of the rock for cement purposes can be determined only by a number of analyses and practical cement tests.

"Better cement can be made by mixing pure limestone with shale, the proportion of each to be determined by careful analysis of the constituents and thorough test of the product. The purer beds in the Stones River, Chambersburg, and Beekmantown limestones are suitable for this purpose, and shale can be procured from the adjacent shale belts. Cement could be commercially manufactured at almost any place in the Stones River limestone areas not too distant from the Martinsburg shale and convenient to the railroad. No plant is established in this area at present."

At one time natural cement was made from some of the limestones near Scotland.

"Stone for local building purposes (5, p. 19) is plentiful in this area, but none suitable for shipment is known. Limestone of convenient thickness for quarrying can be obtained in most portions of the Shenandoah group, and it makes very enduring structures, as attested by the old stone dwellings and artistic arches across the streams throughout the valley. At present it is used very little for building stone, except in foundations, walls, bridge piers, and rubble fences."

"Marble for building or ornamental purposes has not been quarried in this area, but several beds of possible value have been seen. The most attractive bed is a pink marble irregularly veined with green that occurs near the base of the Beekmantown. Several of the purer white limestones of the Beekmantown are finely crystalline marble and have a faint pink tint, but 1½ miles southeast of the village of Clay Hill, the marble has unusually good color. Specimens collected here, although from the surface and considerably fractured, acquire a fine polish. If the color is found to continue with depth and sufficiently large blocks can be quarried, this marble may prove to be of commercial importance.

"Other beds of marble, probably of little commercial value, observed in the area, are as follows: A fine-grained milk-white marble, badly sheeted, in the Waynesboro formation 1 mile northeast of Waynesboro; a coarse mottled reddish variety in the Conococheague limestone in the vicinity of Scotland; a black conglomerate with reddish pebbles near the base of the Beekmantown, seen in both the Chambersburg and the Mercersburg quadrangles; light-colored fine conglomerates and oolites in the Chambersburg and Beekmantown formations of both quadrangles; and layers of concentric, wavy *Cryptozoon* at the base of the Conococheague near Falling Spring and Zentmyer that make 'bull's-eye' marble when polished parallel to the lamination."

As in other portions of the State where limestones of the same age are found, the Cambro-Ordovician limestones have been worked extensively for road ballast and for concrete within recent years. Most of the improved roads of the county pass through the limestone areas and consequently suitable material is near at hand. With the exception of the most pure and consequently soft rocks and the decidedly shaly types practically all the other limestones are suitable for these uses. With so wide a distribution of satisfactory stone for concrete

and ballast it has been possible to obtain good quarry sites near the towns. The principal quarries for crushed stone are near Waynesboro, Chambersburg, Greencastle, and Mercersburg.

DESCRIPTION BY DISTRICTS

Williamson Area. The most extensive quarry operations in Franklin County in recent years are those of the J. E. Baker Co. at Williamson. Four quarries have been worked there by the company to supply stone for burning lime, for blast furnace flux, and for plate glass manufacture. In 1930 two of the quarries, one located just south of Williamson and the other just to the north of the town had been abandoned. One located about half a mile to the northwest of the town was under lease to Harry T. Goetz and the only one in operation by the company was a comparatively new one located about three-fourths mile south of the town. In all of these the stone worked has been a high grade band in the Stones River formation. The following analysis shows the grade of stone that has been obtained.

Analyses of limestone in Baker quarry near Williamson, Franklin County

$CaCO_3$	95.60	97.05
$MgCO_3$	2.80	1.88
Al_2O_3, Fe_2O_3	.70	.40
SiO_2	.90	.67

In the quarry operated by the company the strata dip steeply and are practically vertical in part of the quarry. The width of good stone worked is about 95 feet and the opening is 250 feet long. The quarry is 90 feet deep and worked in two levels, the upper one 60 feet high and the lower one 30 feet. Considerable faulting introduces some quarrying problems. Two fault planes approximately parallel to the strike of the strata form the bounding walls of the quarry. The stone quarried is fine grained and light or dark dove color. A small amount of siliceous and magnesian stone is interbedded with the good stone and must be sorted out and wasted. The wall rock on both sides is highly magnesian. The overburden is light but clay goes downward in old solution pockets to a depth of 60 feet. The rock is drilled, shot, loaded by hand into cars that are hauled up an incline by cable to the crushing plant where it is crushed, screened, and sorted. The plant can produce daily 300 tons of fluxing stone and 40 tons of waste.

The quarry northwest of Williamson under lease to Harry T. Goetz was formerly worked by the J. E. Baker Co. for fluxing stone but the amount of siliceous and magnesian stone that had to be removed and separated from the high grade stone rendered it unprofitable for the quarrying of high calcite stone. Mr. Goetz is operating the quarry for crushed stone mainly, although he has been selling some building stone which has been used in Chambersburg, Mercersburg, and other towns. As the stone is shot down the larger shapely blocks have been put aside for building purposes and the balance crushed.

Several varieties of stone are exposed in the quarry. The dove-colored magnesian stone of the Stones River formation is present. This is irregularly banded in some layers, and contains dark material suggesting dendritic manganese dioxide somewhat like moss agate. The high-calcium stone breaks with a glassy fracture. In one layer promi-

nent sun cracks were noted. Part of the stone is hard, thin-bedded and near the surface breaks into small angular fragments. The strata strike N42°E. and dip 15°NW. The equipment of the quarry is simple. The capacity is about 100 tons of crushed stone daily.

In 1930 G. M. Dietrich was operating a small quarry just south of Williamson narrowly confined between Back Creek and the highway. He has two kilns and gets out some stone to burn in fall and spring for local farm use.

The Williamson area has some stone of high quality and much that is only suitable for use as crushed stone. The folding and faulting are such that careful geological investigations should be made before undertaking the development and operation of a quarry to furnish high grade stone such as is required for fluxing purposes. In some instances prospect work by diamond drilling may be necessary.

Mercersburg Area. The Beekmantown limestone has been quarried in the vicinity of Mercersburg where it contains stone suitable for crushed stone or in some places for construction purposes.

In 1930 two quarries near Dickey Station about 3 miles north of Mercersburg were being worked. At that place George A. Diehl and Harry T. Goetz were operating quarries in the Stones River formation and crushing the stone for highway construction. In the Diehl quarry part of the stone is very pure but most of it is hard and apparently fairly high in silica. It seems to be low in magnesia. The beds strike N6°E and dip 40°NW. The quarry is opened in the side of a hill. There is little overburden and few clay pockets. The quarry face is about 70 feet high and the quarry about 100 feet long and 60 feet wide. The equipment consists of a small tractor steam shovel and two crushers.

The Goetz quarry was opened in 1929. The stone is hard and the beds are massive. The surficial clay is thin except for a number of fairly deep pockets. The beds strike almost exactly north-south and dip 30°W. The quarry opened in the side of the hill is small with the quarry face only about 25 feet in height in 1930. Edgewise conglomerate is prominently developed in one layer. The rock is loaded by a small steam shovel and taken to a jaw crusher to be broken for road use.

Path Valley Area. Limestones belonging to the Stones River, Chambersburg, and Beekmantown formations form the floor of Path Valley from near Cowans Gap to a short distance north of Dry Run village. Throughout this section limestone has been dug for local burning in scores of places. These openings have long been abandoned and the kilns are in ruins. There are a number of attractive stone houses throughout the valley constructed of local limestones. All appear to be old, thus indicating that no building stones have been quarried in recent years. The only recent working seen in 1930 was a small quarry about three-fourths mile south of Fannettsburg where some stone was quarried and crushed for highway use.

The strata exposed are mainly of Beekmantown age and consist of interbedded dolomites and pure limestones. The purer limestones are more conspicuous in the outcrops as they have resisted erosion better than the more highly magnesian strata. In the vicinity of Willow Hill thin-bedded limestones exposed in road cuts probably belong to the Chambersburg formation. Pieces of rosette quartz from

the upper part of the Beekmantown were observed loose in the soils of the region.

Due to complicated folding the beds dip in different directions at various angles but one may generalize by stating that the strike of the strata is approximately parallel to the trend of the valley and the dip is steep toward one or the other side of the valley.

Martin F. Hammond has been operating a limestone quarry half a mile east of Dry Run village about 6 months of the year for the past 19 years to obtain stone for lime. The quarry is at the end of a small hill close to the contact of the overlying Martinsburg shales. The strata seem to belong to the Chambersburg formation. The stone is dove-color, breaks with a glassy fracture, and seems to be of high quality although no chemical analyses are available. A few hard layers high in magnesia were noted. Bryozoan fossils are prominent on the weathered surfaces.

Until recent years Philip Hammond burned lime at a locality about half a mile to the south.

In 1930 Walker Bros. were working under lease a quarry belonging to Basil Zeigler located 2¼ miles northeast of Dry Run to obtain crushed stone for highway construction. The stone is a hard blue dolomite which weathers white. The beds range in thickness from 10 to 14 inches, strike N50°E. and dip 34°NW. The stone was being loaded by hand and hauled to the crusher.

Two miles southwest of Doylesburg, A. E. Doyle has burned lime in the spring and fall for many years. He has a draw kiln. During the summer of 1930 the quarry was under lease to Walker Bros. who were working it for crushed stone for a road contract. The strata belong to the Chambersburg formation and dip to the northwest beneath the Martinsburg shales only a few hundred feet away. The rock is dark in color, mainly fine textured but in places gnarly. Some lenses contain numerous fossils. The stone is said to make excellent lime. Several solution cavities are exposed but there are no caves of consequence. On account of clay and some surficial weathered layers the stone has to be loaded by hand. The quarry face is about 20 feet high and the quarry was being worked down the dip.

J. E. Campbell has quarried some stone on his farm about one mile south of Doylesburg which he sells to the farmers for open heap burning in winter.

D. Frank Crouse has a quarry at Spring Run in the Beekmantown formation which has yielded stone used on the township roads. Some fossils were noted. In addition to the stone quarried he has gathered loose stone from the fields.

Greencastle Area. Limestone has been quarried in the Greencastle area in different places but in 1930 the only working quarry was that of William A. Diehl located about 2 miles north of Greencastle, a short distance west of the Greencastle-Chambersburg pike. The present operation is only about 4 years old and the product is entirely crushed stone but long ago stone was quarried here and burned for lime. The stone is massive, mainly high-calcium stone, breaks with a glassy fracture and is dove-colored. There are some interbedded very dark colored, almost black, siliceous and magnesian beds that break into angular pieces on weathering. The strata constitute a part of the Stones River formation. Many calcite veins cut through

the beds. The present operation is small, the working face about 18 feet in height, but the length of the quarry is about 150 feet. The overburden is 1 to 2 feet thick. In addition there are occasional clay pockets. The daily capacity is about 60 tons of ballast and 20 tons of chips and dust.

A quarry about one mile west of Upton, formerly worked by Bitner and Goetz, is abandoned. This quarry furnished building stone for a dormitory at Wilson College, Chambersburg.

Waynesboro Area. A number of quarries have been worked in the Elbrook formation in and near Waynesboro. The massive stone is well adapted for road ballast and concrete although it is associated with worthless shaly bands in many places. The principal operation in 1930 in this section was that of the Hess Stone and Supply Co. in the southwest part of Waynesboro. Until 1927 this quarry was operated by the Decarbonated Lime and Stone Co. The quarry exposes a series of rather thin-bedded light yellow and gray beds overlying hard massive blue limestones. In the east end of the quarry, which is about 400 feet long and has a working face of 85 feet, the overlying series is 45 to 50 feet thick but where work was being done in 1930 it was only 30 feet in thickness. All of the blue stone and the bulk of the yellow variety are accepted for the State highways but some soft, sandy, ferruginous, interbedded layers must be discarded. There are some variations of dip and strike but in general the beds dip 20°SE. The stone is loaded by hand and hauled in trucks to the jaw crusher. Some of the screenings are made into cement blocks. The capacity of the plant is about 150 tons of crushed stone per day.

The owners of this company, Daniel and Floyd Hess, formerly worked a quarry about 3 miles east of Waynesboro and more recently another one about a mile south of the town. The latter was operated for four years.

Since 1927 J. A. Wishard has been working an old quarry about 2½ miles northwest of Waynesboro. The length of the quarry face is about 200 feet and the height 50 feet at highest point. The rock is a very uniform dark, massive, dolomitic limestone. The upper weathered layers show thin laminae. The overburden of stiff clay is thin except in the numerous clay pockets from 3 to 5 feet deep. This clay must be removed from these pockets by hand shovel. Only crushed stone is being produced. The capacity is about 100 tons per day. The stone is loaded by steam shovel. There are 2 jaw crushers with separate rotary screens and bins.

Chambersburg Area. Much stone from the Beekmantown, Stones River, and Chambersburg formations has been quarried in the vicinity of Chambersburg. Formerly nearly all was burned for agricultural lime but more recently it has been used for crushed stone.

One of the most extensive operations is that of the Chambersburg Stone Co. (Walker Bros.) located about 2 miles east of Chambersburg. The present operators have been in charge since November 1, 1926. The stone worked belongs to the Stonehenge member of the Beekmantown formation. It is a gray to black, hard, magnesian and siliceous limestone well adapted for roads and concrete. It is fairly uniform. The quarry has a face about 200 feet long and 80 feet high. It has been advanced into the hill to a distance of about 300 feet. There is little general stripping but some clay pockets 3 to 4

feet deep. The beds strike N35°E. and dip SE80° or more. The quarry is well equipped with a steam shovel and three sets of jaw crushers. The capacity of the plant is 250 tons per day.

J. S. Brumbaugh was working a quarry on the north side of Falling Spring, just west of Stoufferstown, in 1930 and supplying the Borough of Chambersburg with crushed stone. The quarry is a new one and small. The strata belong to the Beekmantown formation. Some layers are low in magnesia and break with a glassy fracture but most of the stone is highly magnesian. Clay pockets are troublesome as in most newly opened quarries. The beds strike N45°E. and dip 40°SE.

Two quarries in the southwest part of Chambersburg were worked a few years ago for crushed stone.

A marl deposit has recently been reported near Stoufferstown but no definite information concerning it is available.

Beautiful (Salem) Area. North and northwest of Beautiful (Salem) the Stones River limestone has been quarried and burned in a number of places. Most of these quarries are long since abandoned. In 1930 Aaron Ebersole was working an old quarry about one mile north of Beautiful. Most of the stone was crushed for the roads but he has two kilns and burns some lime each year. The lime is said to be of good quality. The stone quarried is mainly dark blue and apparently high in magnesia but some olive gray beds are very pure.

A short distance away David Zook has a quarry which was leased during 1930 to a Mr. Miller, who produced a small amount of crushed stone.

Z. S. Brenize has a quarry at Pinola where he burns about 1200 tons of agricultural lime a year. He has 3 draw kilns. The present quarry is small and has been in operation only a few years but stone was previously obtained from other openings nearby. The stone appears to be of good quality but the beds are badly fractured and faulted.

It is impossible in this report to publish descriptions of all the numerous quarries that have been operated in the Cambro-Ordovician limestones of Franklin County but the foregoing descriptions of active or recently worked quarries indicate the wide variety of limestone present in the different parts of the county.

D'Invilliers (3, p. 1522) gives descriptions of several limestone quarries in Franklin County, most of which have long since been abandoned.

Analyses of Cambro-Ordovician limestones of Franklin County

	1	*2*	*3*	*4a*	*4b*
$CaCO_3$	89.178	54.393	51.743	97.321	67.257
$MgCO_3$	.961	42.694	43.436	1.286	30.702
SiO_2	8.840	2.160	4.090	.980	1.760
$Al_2O_3 + Fe_2O_3$	.806	.941	.222	.260	.700
P	.050	.013	.013	.005	.007

1. Mine No. 3, Mont Alto Iron Co., Mt. Alto.
2. Mine No. 4, Mont Alto Iron Co., Mt. Alto.
3. Shiery quarry, 1½ miles northeast of Mont Alto.
4. S. Z. Hawbecker's quarry, Williamson. a. Best quality stone. b. Poorest quality stone.

All of the above analyses are taken from 4, pp. 80-81.

HELDERBERG LIMESTONES

The Helderberg limestones are present in Little Cove in the southwestern corner of Franklin County. Stose (5, pp. 11-12) has described these limestones as follows:

"Massive dark crystalline coralline limestone forms the lower part of the formation, and fossiliferous cherty limestone the upper part. The crystalline bed was seen about 1 mile northeast of Woods, where about 30 feet is exposed, the lower massive portion being a coral reef of *Favosites* and the upper portion shaly and thin-bedded limestone. One bed containing numerous *Stromatopora* and corals emits a peculiar fetid odor when struck by the hammer. The upper part of the formation is represented at the surface almost solely by numerous chert fragments, which form projections and flat-topped ridges on the lower western slope of Cove Mountain. The thickness of the formation can be only approximately determined as 300 feet. In adjacent portions of Maryland and West Virginia it measures from 380 to 425 feet."

CALCAREOUS MARL

Some calcareous marl deposits in Franklin County have been described by J. B. R. Dickey (6, p. 8) as follows:

"Back of mills in Chambersburg, Falling Spring Branch cascades over a considerable body of consolidated marl the extent of which could not well be determined. The marl is discolored to a brownish yellow.

"About 1½ miles east of Chambersburg where the above stream crosses the Lincoln Highway is a deposit of rather granular and more or less reworked marl on the north side of road. Deposit here is rather small but marl is said to occur in several places along this stream toward Chambersburg.

"On farm of Mr. Bruce Lehman, about 2 miles southwest of Waynesboro, a deposit of marl covering about 15 acres occurs in a bottom along one side of which flows a small stream. The deposit is covered with 6 to 10 inches of dark gray, rather heavy soil. The marl was rather dark gray in color and inclined to be sticky. At one point where some had been dug out, cemented chunks or slabs were encountered. The depth of the marl could not be determined with a 40-inch auger. Samples tested 73 to 84 per cent carbonate in a barely air dry condition. A previous report on this deposit gives analysis of 90 per cent carbonate and a depth in places of 18 feet. This is one of the largest deposits so far encountered but is too far from a railroad for commercial development.

"On the farm of Ellis Kuhns, about 2 miles southeast of Greencastle, a deposit of marl is reported but has not been investigated.

"On the farm of Mr. U. G. Shook, about 2 miles west of Greencastle, just south of the Mercersburg road, is a large, promising and interesting deposit. A stream rises below the house and crosses the road at a mill. Marl is exposed at the road crossing and extending down back of the mill for some distance. The stream below the road falls 25 or 30 feet, and at one point has cut a straight bank down through marl for 20 feet. The marl is largely uncovered and is used for a truck patch beside the mill. In texture it varies from granular on the surface to finer below. In analysis it showed 85 to 90 per cent carbonate.

On account of the deep stream channel this deposit is exceptionally well drained. It is easily accessible from the road, requires no stripping of surface soil and seems to contain no coarse material. It is too far from a railroad for commercial development and is located in a section where lime has been used liberally and the present need is not great.

"Mr. Ed. Hess at Brown's Mills about 3 miles northeast of Greencastle, has a deposit of marl in a field across the road from an old stone mill. This deposit forms a terrace 8 or 10 feet above the stream. The marl is covered with brown surface soil on top of the terrace, but shows in washes on the slope. It does not seem to occur on lower level; probably having been eroded off. This marl is rather granular and carries 80 to 90 per cent carbonate. The deposit covers several acres, is well drained and could be easily developed to supply local needs."

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FULTON COUNTY

The limestones of Fulton County belong almost exclusively to the Cambro-Ordovician and Helderberg series although there are a few other thin limestones of little value in some of the other Paleozoic formations. As no railroad enters the county the stone industry has been altogether local. The principal use has been for agricultural lime but in a few places they were once quarried for flux in blast furnaces and for building purposes. There are some fine old homes constructed of local limestone particularly in McConnellsburg. With the advent of concrete and hard-surfaced roads, some of the old quarries have been worked to supply crushed stone. Because of the rugged topography hard roads are greatly needed and it is fortunate that satisfactory stone for this use can be readily obtained.

CAMBRO-ORDOVICIAN LIMESTONES

The limestones of Fulton County of Cambro-Ordovician age are confined to McConnell's Cove, a longitudinal, anticlinal, canoe-shaped valley in the eastern part of the county. The limestone area is about 3 miles wide in the widest portion but narrows both north and south. It extends about 8 miles north of McConnellsburg and 10 miles south.

The largest quarry in the county is on the west side of Cove Creek about three-fourths mile south of McConnellsburg on a farm belonging to Patterson Bros. The State Highway Department has operated the quarry to secure stone for the State highways in that section. The strata have a strike of N20°E, or in some places almost N-S and dip to the northwest to west at angles of 20° to 30°.

The quarry face in 1929 was about 400 feet long and had been advanced into the hillside to make the working height about 80 feet. Most of the beds consist of hard, compact, blue stone, high in magnesia and in some layers fairly siliceous. This hard stone is excellent for crushed stone. Interbedded with the good stone are a number of sandy and shaly layers containing many cavities lined with calcite crystals. This stone must be discarded. In addition the stone is badly weathered for some depth from the surface and there are clay seams and open joints. It is estimated that only about 60 per cent of the stone quarried can be used. Crossbedding was noted and also numerous aragonite and calcite veins. A few of the calcite veins contain purple fluorite. The stone is crushed at the quarry and hauled in trucks.

C. J. Brewer opened a small quarry 2 miles south of McConnellsburg about 1917. It is well located for development and requires no stripping. The following analyses are from samples taken by him in 1917 and 1922.

Analyses of Cambro-Ordovician limestone from McConnellsburg
(Pennsylvania Bureau of Chemistry, analyst)

No.	*D-51*	*D-53*	*D-249*	*D-250*
CaO	36.45	30.20	48.11	27.72
MgO	8.95	17.49	4.95	17.91
Insoluble matter	12.65	4.66	3.10	11.30
$CaCO_3$	65.01	53.88	85.82	49.47
$MgCO_3$	18.72	37.57	10.35	37.46

A quarry in this limestone on the Walter Gress farm 2 miles southeast of McConnellsburg has a face about 60 feet long and 30 feet high, but it has not been worked in many years. C. H. Stenger quarries limestone on the Geo. Magsam farm in the same vicinity from a face 40 feet long and 12 feet high. The stone is burned in an open heap and used for both building and agricultural lime.

The Cambro-Ordovician limestones have been worked recently by a Mr. Morton in two quarries about one mile south of Webster Mills. About 500 tons of stone was obtained from here in 1928 for bridges on

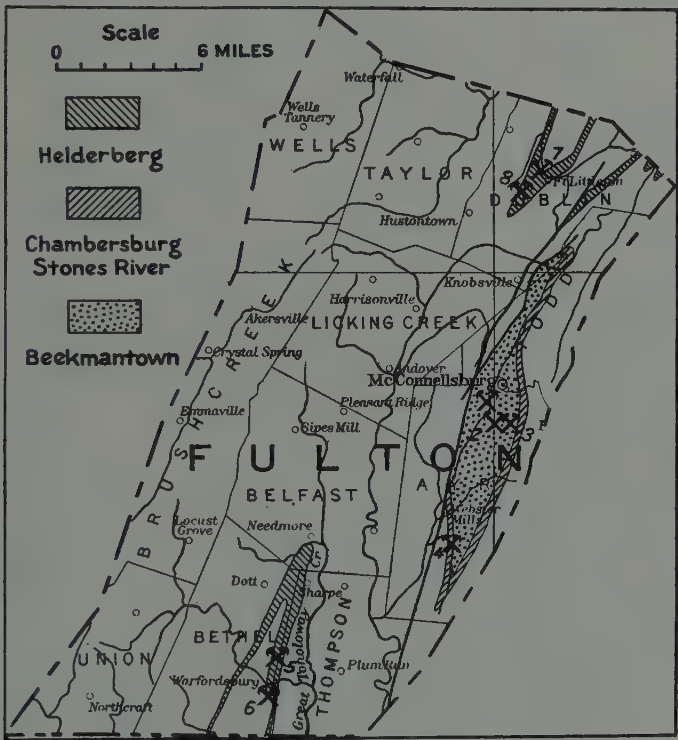

Fig. 15. Limestone areas in Fulton County.

1. Patterson Brothers. 2. C. J. Brewer. 3. C. H. Stanger. 4. Morton quarry. 5. G. Edward Golden. 6. Daniel Rank. 7. Leon Stevens. 8. John S. Wollett.

the highway close at hand. In the northernmost opening the beds strike N57°W. and dip 16°SW. A large spring comes from the limestone near the quarry. The section is as follows:

Section at Morton quarry, one mile south of Webster Mills

	Ft.	*In.*
Bluish-black high calcium limestone, with chert nodules and limestone conglomerate	3-4	
Sandy limestone, light gray to buff, feebly crossbedded	2	1
Compact bluish-black limestone breaking irregularly, similar to upper bed but without chert nodules	3	4
Massive bluish-black limestone	9	10

There seems to have been little quarrying of the Cambro-Ordovician limestones north of McConnellsburg although here and there small quantities have been dug from the fields and burned in open heaps. About 5 miles north of McConnellsburg, near Knobsville, a small circular heap of stone and wood in alternate layers and covered with clay was observed in the process of burning. The stone had been obtained nearby.

Additional analyses of Cambro-Ordovician limestones of Fulton County

	1	2
$CaCO_3$	76.964	51.143
$MgCO_3$	19.327	39.301
Al_2O_3 / Fe_2O_3	0.840	0.660
SiO_2	2.820	9.040
S	0.140	0.207
P	0.005	0.003

1. Farm of John Sowers, Ayr Township. 2. Greathead quarry, McConnellsburg. Analyses by A. S. McCreath (2, p. 336)

HELDERBERG LIMESTONES

The Helderberg limestones of Fulton County are almost entirely confined to Dublin Township in the northeast part of the county, in and about Fort Littleton and Burnt Cabins, and Bethel Township in the south central part, from near Needmore southward through Warfordsburg to the Maryland state line. A limited area of outcrops occurs in Thompson and Ayr townships.

There has never been any large quarry operations in the Helderberg limestones of the county, but locally they have been quarried in many places. Some of the strata consist of high grade limestones but these are generally interbedded with less pure beds of limestone or with shales. The principal use made of these limestones has been for agricultural lime although some have been quarried for building purposes. Some houses constructed of these stones are very attractive. The lime burning has been carried on in upright stone kilns, in temporary clay kilns held in place by a framework of logs, and by open heap roasting. Between Needmore and Warfordsburg small quarries have been worked on many farms, including those of Oliver Hill, Moses Hess, Job Hess, Frank Fisher, Henry Garland, and others. Quarries are located in the valleys of Licking Creek (lower part), Pigeon Cove (south of Needmore), and White Oak Run.

The most important operation in this section seen in 1929 was the quarry of G. Edward Golden, located about 2 miles north of Warfordsburg, close to the highway. He has 2 draw kilns and has at times burned as much as 12,000 bushels of lime a year but does much less now. The lime is crushed and sold to the farmers. The stone being worked is bluish-gray to bluish-black, in fairly thick beds but interbedded with some shale that must be discarded. Calcite veins are prominent. The quarry is a narrow cut that has been extended along the strike of the best strata. It is about 150 feet long, 35 to 40 feet wide, and with a face 40 feet high. A similar quarry on the opposite (east) side of the road was worked at one time.

On the Daniel Rank farm about one-fourth mile southeast of Warfordsburg there is a quarry that at one time furnished considerable building stone. The quarry was opened in the side of a hill, is about

100 feet long, and has a face 18 to 20 feet high. The rocks dip to the east at 15 to 20 degrees. Beneath a 3-foot layer of gnarly limestone containing many Stromatoporoid coral fossils there are massive layers of dark blue, fine-grained limestones that break with a glassy fracture. There are some useless thin layers of limestone above the coral layer. The quarry was opened many years ago for stone to build the house now owned by W. B. Rank. The aqueducts on the canal at Hancock, Maryland, also were built of limestone from this quarry. In recent years rock was taken from this quarry to build the State road through Warfordsburg. At present the quarry is worked only occasionally by Mr. Rank for stone that is hauled to farms within a radius of 10 miles and burned in open heaps for agricultural lime.

In Dublin Township a number of small quarries have been opened. In the vicinity of Fort Littleton the limestone has been quarried for local use on several farms. Three-fourths mile north of Fort Littleton on the Leon Stevens farm, shallow excavations have been made for several hundred feet along the outcrop of a bluish-black limestone that breaks with a glassy fracture. There are numerous white and pink calcite gash veins and stylolites, some of which are at right angles to the bedding planes. The beds are thin, ranging up to one foot thick, strike N.10°E., and dip west 30° into the hill. At a depth of 10 feet or less, sinking down the dip is stopped by the difficulty of getting the rock up over the lip of the quarry. One or two men work here intermittently and burn the rock in a draw kiln. This quarry was worked last by the contractor building the road through Fort Littleton.

On the John S. Wollett farm 2 miles southwest of Fort Littleton a quarry face 200 feet long and up to 30 feet high exposes a massive-bedded, dark blue, mottled, and fossiliferous limestone. The beds strike N.30°E. and dip 30°NW. Vertical joints are conspicuous and calcite veinlets are common. This quarry and its draw kiln, which are hidden in the woods, were idle for several years. The quarry was under lease to the State for highway material in 1929.

About 500 feet south of the Wollett quarry are several small excavations in limestone on the John Martz farm. Here the bedding is nearly vertical and the high-grade, deep blue rock is separated by bands of impure shelly limestone several feet thick. Limestone was quarried here until 1921 and burned in open heaps for agricultural lime. Similar small excavations have been made on nearby farms for the same purpose. R. M. Cline, near Fort Littleton, has worked a small quarry for his own use.

Near Burnt Cabins there are several small quarries, some of which have been worked in recent years to obtain agricultural lime.

Analyses of Helderberg limestones of Fulton County

	1	2	3
$CaCO_3$	93.117	87.357	91.303
$MgCO_3$	2.043	2.346	2.043
Al_2O_3 & Fe_2O_3 .	.600	1.930	.810
SiO_2	4.110	8.430	5.550
S	.075	.020	.201
P	.006	.002	.004

1. Fisher quarry, Bethel Township (2, p. 274)
2. Johnston quarry near Licking Creek, Thompson Township, about 2 miles from the Maryland state line (2, p. 291)
3. Ramsay quarry, one-third mile north of Fort Littleton (2, p. 304)

OTHER PALEOZOIC LIMESTONES

In the Clinton, Salina, Oriskany, Onondaga, Marcellus, and Hamilton formations of the State there are occasional thin limestones that have been worked in a few places on a small scale. It is probable that there are some within Fulton County, although none were observed by the writer. Stevenson (2) reports some Oriskany sandstone occurring in Ayr Township sufficiently high in $CaCO_3$ that it was burned for lime.

The Pocono, Mauch Chunk, and Pennsylvanian strata are well developed in the western and northwestern part of Fulton County and doubtless they too contain some limestones that locally may be of some slight economic importance. Stevenson reports some Mauch Chunk limestone in Ayr Township that was once quarried. These limestones have not been investigated by the writer.

The Mauch Chunk red shale that is exposed as a band up to 3 miles wide surrounding Broad Top and extending northward in Little Trough Creek valley about 12 miles and southward a greater distance in the west part of Fulton County contains considerable limestone interbedded with shales. Most of the limestone is red and quite impure, containing up to 40 per cent of siliceous material, yet it has been utilized for agricultural lime locally. Some gray layers are purer. These limestones of the Mauch Chunk series seem to represent the Greenbrier limestone of the region on the west.

CALCAREOUS MARL

J. B. R. Dickey describes a deposit of calcareous marl in Fulton County as follows (4, pp. 8-9):

"The only known deposit in Fulton County is on the farm of Mr. Job C. Hess, about 4 miles north of Warfordsburg, in a small limestone cove. The deposit covers about ½ acre near Mr. Hess' house. It was no doubt formed by a spring which rises just above and which has been piped to the house so that the deposit is now well drained. It lies in a sort of pocket, well above the level of the nearby drainage. The color is almost pure white and samples are reported to anaylze as high as 93 per cent lime. The deposit is covered with a few inches of dark surface soil. Depth of the deposit was not determined but is over 5 feet.

"Mr. Hess has developed this deposit in a small way during recent years. The marl is scooped out in dry weather, screened and sold at $3 per ton or 13.5 cents per bushel. A bushel, air dry, weighs about 90 pounds, and since the moisture varies it is fairer to the purchaser to sell by measure than by weight. About 100 tons were sold from this deposit in the fall of 1921. Applications were often made with a grain drill as light as 1000 pounds per acre or less and results on wheat and clover were reported very satisfactory. Applications on the home farm were heavier and results consequently better.

"This deposit has special value because it is in a section too far from a railroad for commercial lime to be available, and where there is no coal with which to burn lime."

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In the descriptions of the limestones of Greene County, the writer is indebted to R. W. Stone, Assistant State Geologist, for the major portion. All quoted paragraphs, not otherwise credited, are abstracted from his report on the Geology and Mineral Resources of Greene County.

A number of limestones have been recognized throughout Greene County although most of them are locally developed and do not extend through the entire county. Many of them have been worked to supply stone for agricultural lime, some for plaster lime, some for flux in iron smelters, in glass manufacture, for pulverized limestone for farm use, and several have furnished material for the roads. For the latter purpose much of the stone is condemned as it has a tendency to disintegrate rapidly when exposed to the weather. Some of these limestones have been accepted by the State Highway Department in the construction of water-bound macadam roads but rejected for concrete roads.

Practically all of Greene County has been mapped since 1900 by the U. S. Geological Survey and the results published in Geologic Folios Nos. 82, 121, 146. Much of the data contained in this section is abstracted from these folios with minor changes. Bulletins Nos. 65 and 249 of the U. S. Geological Survey and Report K of the Second Geological Survey of Pennsylvania contain much valuable information, especially several local sections. There is considerable lack of agreement in these various publications which cannot be discussed here. The generalized section given below is compiled from these sources.

Generalized geologic section of Greene County

	Maximum thickness in feet
Permian (Dunkard) series	
Greene group	750±
Windy Gap limestone	
Windy Gap coal	
Gilmore sandstone	
Nineveh sandstone	
Nineveh coal	
Nineveh limestone	
Hostetter coal	
Fish Creek sandstone	
Dunkard coal	
Tenmile coal	
Washington group	400±
Upper Washington limestone	
Jollytown limestone	
Jollytown coal	
Middle Washington limestone	
Blacksville limestone	
Lower Washington limestone	
Washington coal	
Little Washington coal	
Waynesburg "B" coal	
Colvin Run limestone	
Waynesburg "A" coal	
Mount Morris limestone	
Waynesburg sandstone	
Pennsylvanian	
Monongahela group	370±
Waynesburg coal	
Waynesburg limestone	
Uniontown coal	
Benwood limestone	
Sewickley (Mapletown) coal	
Fishpot (Sewickley) limestone	
Redstone coal	
Redstone limestone	
Pittsburgh sandstone	
Pittsburgh coal	

In the above section the named beds in each group do not constitute the entire strata. On the contrary, shales predominate but the various shale strata have not been given specific names.

Distribution of the geological formations. The geologic maps contained in the folios show the distribution of the various geologic for-

mations. These show the Monongahela group outcropping in the eastern part of the county, along Monongahela River and appearing in the valleys of the tributaries for a distance of four to six miles. In the valley of Tenmile Creek the group outcrops to within a mile of Waynesburg. The group is also sparingly represented in the valleys of a few streams in the northwest corner of the county.

The Washington group of the Dunkard series occupies the divides in the vicinity of Monongahela River and extends up the tributaries as far west as Rogersville. It also appears in the valleys of the streams in the northwest portion of the county.

The western half of the county is almost entirely underlain by the Greene group with the exception of some of the valleys mentioned above. It is the most extensively exposed group of the county.

LIMESTONES OF THE MONONGAHELA GROUP

Redstone limestones. "The Redstone limestone (3, pp. 145-6) closely underlying the coal of that name, crops out only in the valley of Monongahela River or close to it. Elsewhere in the county it is deeply buried. Although it appears to be lacking in the section at Rices Landing, the space between the Pittsburgh and Redstone coals being occupied by massive and flaggy sandstone, a few miles farther up the river this limestone is well developed.

"The following description of the occurrence and section at Alicia No. 2 mine is by J. D. Sisler, of this Survey.

"'At the Alicia No. 2 mine of the Pittsburgh Steel Company, located on the Greene County side of Monongahela River near Grays Landing, there is an interesting outcrop of limestone above the Pittsburgh coal bed, which at this point is about 20 feet above water level. The limestone, somewhat stratified with shale, is about 30 feet thick, and analyzes over 90 per cent $CaCO_3$. A cut made for a tram road along the river bank uncovered this gray hard limestone and clearly exposed a considerable part of its thickness. It weathers yellow and is in layers of varying thickness.

"'Where the tram road turns away from the river up a gully to the drift mouth, the character of the material overlying the coal bed undergoes considerable change, and instead of limestone or shale one finds reddish debris, without stratification, broken up and soft, and with a tendency to slide down on the tram road. In this broken-up mass several lumps of slag were found. There is no coal under this debris for a distance of 400 feet from the outcrop.

"'According to the mine superintendent and Mr. Girod, State Mine Inspector (23rd District), this missing coal has been consumed by rapid oxidation, reaching such a temperature that the overlying limestone was burned and in some cases actually fluxed, forming slag. A forest fire may have ignited the outcropping coal. This unusual condition is found only at the mouth of the gully.'

Section at Alicia No. 2 Mine

	Feet		Feet
Shaly sandstone	20	Shale	20
Sewickley coal	5	Redstone coal	3
Shale	5	Limestone	10
Limestone	3	Limestone and shale	20
Shale	3	Shale	5
Coal	0.5	Pittsburgh coal	13
Limestone	5		

"In this section, which was measured by Mr. Sisler, the limestone below the Redstone coal is a fairly solid bed, but the succeeding 20 feet is composed of several beds or lenses of limestone, of varying composition and hardness, and more or less interstratified with shale which is included in the measurement. Should this 10-foot limestone be of commercial value, several thousand tons of it could be quarried readily between the present tram and the steep rock bluff behind it. Shipment could be made by river barge.

"This limestone is reported to make lime of fair quality, and some of it might be satisfactory for road metal.

"Stevenson describes the section half a mile above Grays Landing as containing 25 feet of calcareous sandstone at this horizon, and mentions 16 feet of limestone in a ravine by the old glass works at Greensboro.

"No use is now being made of the Redstone limestone in Greene County unless it is the rock quarried by township commissioners on the south bank of Tenmile Creek below Trumbull. The base of the bluff is accessible to wagons in summer and a quantity of stone has been taken here for road metal."

Fishpot limestone. "The Fishpot limestone (3, p. 146) which lies below the Sewickley or Mapletown coal, is exposed in the bluff of Monongahela River between the mouth of Tenmile Creek and Bush Run. It is 25 feet thick with sandstone above and sandy shale below, but difficult of access. About half a mile above Grays Landing, this limestone is in two benches, 15 and 8 feet thick, separated by 10 feet of shale.

"At Alicia No. 2 mine the section on a preceding page shows this limestone in two beds, 3 and 5 feet thick, separated by 3 feet of shale and a 6-inch coal bed.

"Near the State line in Dunkard township the Fishpot limestone is one bed 8 feet thick with sandstone below and shale above.

"It is probable that some geologists, especially those familiar with the stratigraphy of the Panhandle of West Virginia, would call the 3-foot limestone that lies 5 feet below the Sewickley coal at Alicia No. 2 mine the Sewickley limestone, and correlate it with the 15-foot limestone found 8 feet below the Sewickley coal near Grays Landing. No objection can be offered to this, but the thick limestone below Rices Landing is maintained to be the Fishpot because it is 40 feet below the Sewickley coal.

"The quality of the Fishpot limestone is said not to be equal to that of the Benwood limestone. This statement needs further qualification for there is a great variation in composition of different beds of the overlying Benwood limestone. Analyses of the Fishpot limestone in Greene County are not available and the writer does not know any place in the county where it is quarried."

Benwood limestone. "In the midst of the Monongahela group (3, pp. 143-5), or halfway between the Pittsburgh and Waynesburg coal beds, is the Benwood or Great limestone. In places it is 150 feet thick and a conspicuous stratigraphic horizon. The name is derived from an excellent exposure of this limestone at Benwood 4 miles south of Wheeling, W. Va. It is commonly known also as the Great limestone.

"The term Benwood limestone is restricted to the strata occurring between the Sewickley and Uniontown coals. This bed is never solid limestone, being broken up by layers of shale and thin sandstone into two large divisions. The lower division is about 60 feet thick, and is generally composed of alternating bands of limestone and calcareous shale. The limestone beds are usually less than two feet thick, although an occasional bed is 6 to 10 feet thick locally. The upper division of the Benwood limestone is of varying thickness, from 6 to 20 feet, and lies immediately under the Uniontown coal. It is composed of beds a foot or more thick with interstratified thin layers of shale. The lower division is more persistent than the upper and has a larger magnesian content. The analyses of samples collected by the writer in 1925 and those published by the Pennsylvania Second Geological Survey indicate that the composition is variable. The weathered surface of the limestone may be gray, almost white, bluish, or brownish; the fresh stone is dark blue, flesh colored, and drab.

"Certain benches are pure enough for making lime while others are worthless. The texture varies from very fine to shaly. This limestone was used years ago in the Monongahela Valley for making natural cement, but its only use in Greene County, at the time of this writing, so far as the writer discovered, is for road metal. Nearly all of the beds might be used for agricultural purposes, but only a few would yield a strong building lime. The soil derived from the weathering of this limestone is rich, and makes good farming land.

"The Benwood limestone is exposed at several places in the bluff of Monongahela River, as at the Dilworth mine just below Rices Landing where 30 to 40 feet of limestone is exposed as a vertical cliff along the railroad. In the mouth of Pumpkin Run at Rices Landing, this limestone is exposed in quarries in both banks. On the south side of the run a quarry has been opened on a limestone bed about 15 feet thick, and is operated intermittently by the township or boro for road metal. A sample of this limestone collected by the writer from the whole length and height of the exposure shows that it is a magnesian limestone, containing 47 per cent calcium carbonate and 25 per cent magnesian carbonate.

"On the north side of the ravine a quarry on the land of Dr. S. A. Hoge shows the following section.

Partial section of Benwood limestone at Rices Landing

	Feet	Inches	
Limestone	1	3	
Shale, shaly limestone and limestone	7	0	
Limestone, soft	3	4	Analysis 5
Shaly, wavy parting		1	
Limestone	2	0	Analysis 4
Wavy parting			Analysis 4
Limestone	1	0	Analysis 4
Shaly limestone		4	
Limestone .... 15 inches to	1	8	Analysis 3
Shale and limestone	1	0	
Floor, streak of red shale			

"Below the floor of this quarry to the main street of Rices Landing there is approximately 50 feet of limestone, part of which is represented by analysis 2 from the quarry on the south side of the run. Along the road above the quarry on Dr. Hoge's land the rock sequence is 35 feet mostly limestone, 30-40 feet of sandy shale, then 4 feet of limestone that may be the Waynesburg bed.

"Samples collected by the writer in the Hoge quarry show a wide variation in composition. The 20-inch bed of dark limestone just above the floor carries 95.78 per cent calcium carbonate and less than 2 per cent magnesian carbonate, but the 3-foot and 40-inch beds next above have only 65 and 66 per cent calcium carbonate and over 20 per cent magnesian carbonate, as shown by the analyses below. This result is in accord with the report by Stevenson (2) on the composition of the Benwood limestone in Washington County.

"According to I. C. White, the Benwood limestone on the N. C. McClelland farm at the ferry 2 miles above Rices Landing, is 90 feet thick. This is not one solid mass of limestone; the layers of limestone are separated by calcareous shale 6 inches to 1 foot thick, nor is the limestone all of one kind. Mr. McClelland, prior to White's examination in 1875, had quarried and shipped a considerable quantity to the Pittsburgh iron and glass furnaces for flux. Some layers of the limestone will not slack when burned, some make agricultural lime, and some of it is called sodastone, owing to the fact that many years ago it was used in the manufacture of soda at an establishment in Pittsburgh.

"On Bush Run, in a wooded ravine in the northern end of Jefferson Township, the Benwood limestone is exposed in the steep banks below the State Highway. It is in two parts separated by 35 feet of shale and sandstone. The upper part is 8 feet and the lower 85 feet thick. One mile farther north the highway descending to Tenmile Creek crosses this limestone but it is not well exposed. It is in the vertical cliff between the highway and the elbow in the creek.

"At Clarksville the township commissioners have taken Benwood limestone from the bed of Tenmile Creek just above the village and crushed it for road use. A sample taken from stock in the bins at the crusher carried about 85 per cent calcium carbonate. There are particular good exposures of this limestone in Castile Run and at the iron bridge across South Fork of Tenmile Creek 1½ miles below Jefferson. Near this bridge about 15 feet of limestone is exposed in a railroad cut. In this exposure it is noticeable that two lower benches totaling 5 feet thick come together or unite and almost feather out in a distance of 400 feet."

The Benwood limestone is apt to contain deleterious matter in the form of clay that renders it unfit for concrete use in any structures exposed to moisture. A quarry located along Tenmile Creek about one mile south of Clarksville, operated to supply crushed stone for highways and bridges in that section, had to be abandoned because of the serious disintegration of the concrete after a few years. The stone had met rigid specifications of the State Highway Department but microscopic examination furnished the explanation for the failure. This occurrence and the investigation are described in detail in a previous chapter on "Weathering of Limestone."

Analyces of Benwood limestones in Greene County

[Pittsburgh Testing Laboratory, analyst]

	1	2	3	4	5
$CaCO_3$	84.89	47.10	95.78	64.97	66.13
$MgCO_3$	6.50	25.25	1.54	20.76	20.61
Al_2O_3	.91	5.73	.37	1.69	1.60
Fe_2O_3	1.29	1.57	.43	1.43	1.00
SiO_2	4.52	17.32	.96	8.96	7.20
TiO_2	Tr.	.10	Tr.	Tr.	Tr.
Loss on ignition (other than CO_2)	.94	1.51	.61	.39	1.96
Alkalies and undetermined	.95	1.42	.31	1.80	1.50

1. From bin of crusher operated by Commissioners of Morgan Township at Clarksville.
2. From face of quarry by railroad underpass on south side of ravine at Rices Landing. Represents 15 feet of bed apparently lower than No. 3.
3. 20-inch dark bed at bottom of Dr. Hoge quarry, Rices Landing.
4. 36-inch bed just above No. 3.
5. 40-inch bed just above No. 4.

Waynesburg limestone. "With fairly wide distribution in the eastern half of the county, the Waynesburg limestone (3, pp. 146-7) may be said to have some prospects of greater use in the future than at present. It makes a strong dark lime, can be used for soil sweetener and for crushed stone, especially in localities not close to a railroad. The Waynesburg limestone is found 20 to 40 feet below the Waynesburg coal throughout Greene County and in southwestern Washington County, but is not present farther north or in Ohio. Its distance below the coal increases from north to south across Greene County. Its thickness ranges from 4 to 10 feet in most places, but a limestone on Dunkard Creek near Davistown 42 feet below the Waynesburg coal is 15 feet thick. On Monongahela River below the mouth of Little Whiteley Creek the thickness of the Waynesburg limestone is 10 feet, below Muddy Creek 9 feet, and below Bush Run 6 feet. The rocks between it and the Waynesburg coal at these places are 35 to 40 feet of shale and shaly sandstone.

"Near Jefferson this limestone is reported to be 7 feet thick but where the writer collected a sample for analysis from the outcrop at the highway concrete bridge over the railroad 1¼ mile southwest of Jefferson only about 4 feet of limestone was found although stripping might disclose a greater thickness. Other places where it is exposed and readily accessible are the lower half of Braden Run, mouth of Browns Run, on the road from Clarksville to Castile Run going over the hills, at the Ferncliff amusement park on Pumpkin Run one mile above Rices Landing, on Muddy Run 1 mile below Carmichaels, three-quarters of a mile east of Whiteley, and in the hollow three-quarters of a mile east of the mouth of Glade Run.

"Below Carmichaels where the Waynesburg limestone lies in Muddy Run, it was quarried and crushed by Hart Brothers of Carmichaels for agricultural limestone. This small recent industry, however, has been abandoned and the machinery removed. The writer collected a sample of the pulverized limestone from the few bushels remaining in the shed and analysis showed 66.84 per cent calcium carbonate, 12.95 per cent magnesium carbonate, and 11.40 per cent silica, which is very

different from the analysis of the Waynesburg limestone from Jefferson in the table below.

Analyses of Waynesburg limestone

(Pittsburgh Testing Laboratory, analyst)

	1	2
$CaCO_3$	66.84	82.56
$MgCO_3$	12.95	5.59
Al_2O_3	4.50	1.83
Fe_2O_3	1.72	1.57
SiO_2	11.40	5.92
TiO_2	.10	Tr.
Loss on ignition (other than CO_2)	1.73	1.24
Alkalies and Undetermined	.76	1.29

1. Pulverized stone from crusher of Hart Bros., Carmichaels.
2. Outcrop at highway concrete bridge over railroad, 1¼ miles southwest of Jefferson.

LIMESTONES OF THE WASHINGTON GROUP

Mount Morris limestone. From 2 to 5 feet below the Waynesburg "A" coal, White (4, pp. 39-40) describes a limestone from 1 to 2 feet thick well exposed along Dunkard Creek near Mount Morris. It is not persistent throughout the county.

Colvin Run limestone. White (4, p. 39) also describes a fairly pure limestone about 3 feet thick overlying the Waynesburg "A" coal. It is named from Colvin Run which is a tributary of Dunkard Creek. The limestone is said to be high in iron in some places, to have a buffish cast, and to be unsatisfactory for lime because of poor slaking when burnt.

Lower Washington limestone. The lower Washington limestone is of little economic importance in Greene County although present in many places in the western part of the county. It occurs immediately above the Washington coal bed (9, p. 3).

Section of Lower Washington limestone 1 mile northwest of Ryerson Station

	Ft.	*in.*
Limestone	1	8
Shale	1	1
Limestone	1	6

Blacksville limestone. From 30 to 50 feet above the Washington coal White (4, p. 36) describes a fairly pure, generally gray limestone from 3 to 5 feet thick that is especially well exposed in the Dunkard Creek region.

Middle Washington limestone. The Middle Washington limestone is not important in Greene County. In the Dunkard Creek region it is about 3 feet thick and contains numerous fossils. The shales accompanying the limestone contain fish scales, teeth, and fossil plants.

Jollytown limestone. "Thirty feet (8, p. 6) above the Jollytown coal and 20 feet below the Upper Washington limestone is a limestone which is exceedingly persistent. It is hard and coarsely brecciated,

weathering to dull gray, often tinged with yellow. The surface frequently has a roughened appearance where weathered. Owing to its ability to withstand the weather and to its peculiar surface characteristics it is an important guide in stratigraphy. It is not more than 5 feet thick, but it is so resistant that some trace of it is usually found wherever it has been exposed. Outcrops are numerous. Along South Fork of Tenmile Creek above Waynesburg in particular, and throughout the western half of the (Waynesburg) quadrangle in general, blocks of the yellow limestone can be found between the Jollytown coal and the Upper Washington limestone.''

This limestone is usually regarded as of no economic value.

Upper Washington limestone. ''About 400 feet (3, pp. 147-150) above the Waynesburg coal and marking the division between the Washington and Greene groups is the Upper Washington limestone which has the widest distribution and longest outcrop of any worthwhile limestone in the county. It is high in the hills near Jefferson and Whitely, near the valley bottoms north and west of Waynesburg, and goes below drainage near Deerlick, Woodruff, and two miles above Rogersville. It comes to light again near Time, Graysville, and McCracken, and is high in the hills near Durbin. This limestone is 4 to 9 feet thick and is readily recognized by its white, weathered surface.

''According to J. J. Stevenson (Report K, page 46) 'In Greene County it is readily identifiable everywhere except in the Fish Creek region. On Dunkard it is quite impure and bears little resemblance to itself as it ordinarily appears. It has been recognized in Morgan, Washington, Morris, Richhill, Aleppo, Centre, Franklin, Greene, Jefferson, Cumberland, Perry, Wayne, and Gilmore townships. Its thickness is from 4 to 8 feet, and the interval between it and the Washington coal varies from 325 feet on Dunkard, to 260 on Tenmile near Waynesburg, 190 on Ruff Creek in eastern Washington, and 135 on Hunters Fork on South Wheeling Creek in Richhill. No difficulty is encountered in following this rock from its northwestern exposure in Smith township, Washington County, to Whitely Creek in Greene township, Greene County.'

''Where the outcrop of this limestone is concealed, its presence usually is indicated by fragments or well-rounded lumps of very white limestone float.

''The writer measured the following section at an old quarry.

Section of Upper Washington limestone near Swarts

	Ft.	*in.*
Shale and limy shale	10	
Limestone		10
Shaly limestone		5
Limestone	2	4
Shaly limestone		6
Limestone	1	
Shaly limestone		5
Limestone		9
Limestone	1	2
Shale		2
Limestone	1	5

''This quarry half a mile north of Swarts is close to the Waynesburg and Washington Railroad and is very noticeable from the high-

way on Bates Fork for it has a face more than 300 feet long of distinctly light color. It is on the Phillips farm, formerly owned by Ben Moore. A company of local farmers opened and operated this quarry to supply the railroad with ballast. Quarry cars were moved over a track of wooden rails to a trestle where they were dumped directly into railroad cars on a spur track, or to a jaw crusher.

"The quarry was last operated by the State Highway Department about 1922, but 10 cars of screenings were shipped from it in 1924.

"Probably the different layers of limestone shown in the section above differ in chemical composition as they do in physical character. The analysis in the subjoined table represents all of the beds combined, but omitting the shaly partings. It agrees very closely with the analysis of Upper Washington limestone at Holbrook on McCourtney Run. In neither place is the limestone of high quality.

"The other sample of Upper Washington limestone, No. 1 in the analyses below, was taken at the fork of the road at the mouth of Hoge Run one-quarter mile below Holbrook. Here in the road bank and in the stream on the W. G. Hoge farm the limestone is well exposed.

Section of Upper Washington limestone at Holbrook

	Ft.	in.
Shaly limestone and limy shale	8	
Limestone, massive, light color	2	8
Shale		6
Limestone, poor knotty		4
Limestone, solid		9
Shale, drab, calcareous	3	
Limestone, dull flesh color		8
Shale		

"The analysis represents only the 32-inch massive bed at the top, which is said to be the only layer in this locality that yields good lime.

"Between Holbrook and the mouth of Pursley Creek the Upper Washington limestone is abundantly exposed on both banks of Tenmile Creek. It is about 7 feet thick and in many places is close above the road.

"On a spur on the north side of Ruff Creek and one-third mile west of Craynes Run the Upper Washington limestone has been quarried by township commissioners for road metal. Under 8 inches of black shale lies 10 inches of grayish limestone, 2 inches of limy shale full of fossil shells, and 30 inches of blue limestone weathering white. This quarry is about 125 feet above the creek.

"The Upper Washington limestone in the quarry near Swarts contains abundant minute fossils, apparently a bivalve crustacean or ostracod. To the naked eye they are little more than black specks but, under a lens, character becomes apparent. They are thought to be fresh-water animals. These fossils seem to be particularly abundant in the 10-inch and 28-inch beds near the top of the quarry face, but can be found by hundreds in the lower beds as well. Many of them are fragmentary.

"A local limestone 2½ feet thick with 1 foot of very bituminous shale above it was burned by David Spragg on Roberts Run more than 50 years ago and the lime used in building his brick house. Bowlders of this limestone occur near Spraggs P. O."

Analyses of Upper Washington limestone

(Pittsburgh Testing Laboratory, analyst)

	1	2
$CaCO_3$	82.93	84.00
$MgCO_3$	2.48	3.10
Al_2O_3	2.56	1.71
Fe_2O_3	1.14	1.29
SiO_2	8.32	7.28
TiO_2	.10	Tr.
Loss on ignition (other than CO_2	.94	.94
Alkalies and undetermined	1.53	1.68

1. Road exposure on W. G. Hoge farm, Holbrook.
2. Quarry ½ mile north of Swarts.

LIMESTONES OF THE GREENE GROUP

The Greene group, so well developed in Greene County, contains a number of thin, impure limestones, most of which are only local. This formation in the county has a maximum thickness of 700 to 800 feet and consists mainly of shales and sandstones with a few thin lenses of coal and limestone. Stevenson (2) has numbered 9 limestones and White (4) has given names to two of these layers.

The so-called Nineveh limestone lies about 105 feet above the Fish Creek sandstone. It is exposed along the North Fork of Dunkard Creek where it is 5 to 10 feet thick. It contains interstratified shale and weathers like shale. A few layers make good lime.

The Windy Gap limestone is present in the extreme northwest part of Greene County where it appears near the top of the highest hills. The limestone consists of several beds, aggregating 8 to 10 feet in thickness. It is a dark-bluish to bluish-black stone weathering to light gray. It has been found to contain minute fossils and occasional small crystals of sphalerite.

ORIGIN OF THE GREENE COUNTY LIMESTONES

"Although the limestones (3, p. 150) below the Pittsburgh coal, from the Ames to the Vanport, are definitely of marine origin, for they contain an abundance of fossils that certainly are the remains of animals that lived in salt water, the origin of the limestones above the Pittsburgh coal is uncertain. The Redstone is an impure limestone and the Fishpot resembles it where it is thin, but where thick it is likely to contain some layers of cement rock. The Benwood is very thick and some of its layers are highly magnesian. Other distinct beds, like the Uniontown, Waynesburg, and Upper Washington limestones are less or only slightly magnesian.

"Their principal occurrence is between the Monongahela and Ohio rivers.

"They can hardly be accounted for as accumulations of fresh-water marl, for the Benwood limestone 80 feet thick on the Monongahela may give place in a very short distance to a nearly equal thickness of shale and sandstone. Nor can it be assumed that they are calcareous muds for there seem to have been no limestone areas on any side from which such muds could be derived by solution or erosion. The highly magnesian beds may alternate with only slightly magnesian beds with

seemingly almost continuous deposition and yet the former are difficult to regard as of fresh-water origin and their marine origin may be questioned because of an apparent almost total lack of marine fossils."

ECONOMIC IMPORTANCE

This review of the limestones of Greene County shows plainly that the county contains an abundance of limestone that can be quarried in a small way to supply local needs for agricultural lime and certain layers furnish satisfactory material for highway construction. On the other hand it is evident that they will never be of more than local value.

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HUNTINGDON COUNTY

A number of different limestones outcrop in Huntingdon County. With the exception of the Cambro-Ordovician limestones in that portion of Nittany Valley included within the county, all of the limestones are found in narrow longitudinal valleys enclosed by high steep ridges. The limestones occupy anticlinal valleys, that is, they mark the position of ridges long since removed by erosion. The sharp mountain ridges that now enclose the present valleys owe their greater altitude solely to the more resistant rocks that compose them. The limestones do not form flat valley floors in most cases; indeed they are present in small subordinate ridges or in rounded hills and valleys in a great many sections.

The limestones have been quarried in a small way in scores, perhaps hundreds, of places. For building foundations, for crushed stone, and for agricultural lime for local consumption almost any of the limestones described might be used; indeed they have been used. In the past when numerous small furnaces in the region were utilizing local ores little attention was given to the amount of silica present in the limestones; the proximity of the quarry to the furnace was more important, and some rather high-silica limestones were used for flux.

The improvement in transportation facilities, the centralization of the iron and steel industry of the State in a few places where large plants have been established, and likewise the change in the lime industry by which the small operators have quit and firms with superior stone have enlarged their plants, have caused the abandonment of most of the small quarries and the development of a smaller number of large operations engaged in quarrying high grade limestones for flux and for lime. Opposed to this trend is the endeavor of the State Highway Department to use local stone so far as possible in building roads. This causes the opening of small local quarries for temporary use. In general, however, road metal and crushed stone for concrete are likewise obtained from the large quarries mainly worked for flux and for lime, as the small sizes produced in quarrying and crushing are useless for these purposes and can only be sold for crushed stone. Necessarily the cost of operation is also less in a large, well-equipped quarry, so the small quarry can compete only where it is so located with respect to the road under construction that a long and expensive haul is avoided.

The generalized section of Huntingdon County has been offered by Charles Butts (4, pp. 531-534) and is here quoted with slight modifications to bring it into accord with the classification accepted by this Survey.

*Geologic column for Blair and Huntingdon Counties**

*This column has been arranged to follow the official section of the Pennsylvania Geological Survey although the author prefers to U. S. Geological Survey classification which does not include the Canadian system.

	Feet
PENNSYLVANIAN	
Allegheny group	200 ±
Shale and sandstone, with workable coal beds.	
Pottsville series	130-280
Mainly sandstone, clay and shale, with coal locally in middle.	
Homewood sandstone	
Mercer shale	
Connoquenessing sandstone	

MISSISSIPPIAN	
Mauch Chunk series	180-1000
Mainly lumpy, red shale or mudrock. Mostly of Chester age.	
Loyalhanna limestone—Trough Creek limestone	
Siliceous cross-bedded limestone to west (Loyalhanna limestone); gray and red, partly argillaceous limestone to east (Trough Creek limestone of I. C. White)	
Pocono series	1130-1400
Thick-bedded, gray sandstone; Burgoon member at top; shale, red shale, and sandstone below. Conglomerate at bottom to east. Osage age.	
Burgoon sandstone	
Cuyahoga sandstone	
Berea sandstone	
DEVONIAN	
Upper Devonian	
Catskill group	2000-2500
Lumpy, red shale or mudrock, thick-bedded, micaceous red sandstone. 80 per cent red. Gray and greenish shale and gray sandstone with marine fossils, 20 per cent.	
Chemung group	2400-3300
Mostly shale with thin sandstone layers.	
Saxton conglomerate	
Allegrippis sandstone	
Pine Ridge sandstone	
Portage group	
Brallier shale	1350-1800
Fine-grained, siliceous shale in thick, even layers revealing their fissility on weathering. A few thin fine-grained sandstone layers. Fossils small and very scarce. Upper Portage.	
Harrell shale	250
Dove and black fissile (paper) shale. Black at bottom to west Burket member. Black and dove interbedded to east.	
Burket black shale	
Middle Devonian	
Hamilton group	800-1200
Hackly shale at top, weathers green; impure limestone layers in top 10 to 20 feet.	
Tully, limestone—1 foot limestone at very top	
Marcellus shale	150
Black fissile shale	
Onondaga group	50
Dark shale with limestone layers	
Lower Devonian	
Oriskany group	
Ridgeley sandstone	100
Coarse thick-bedded sandstone. Common Oriskany fossils plenty. Upper Oriskany.	
Shriver limestone	200
Thin-bedded siliceous limestone. Oriskany fossils. Lower Oriskany.	
Helderberg group	150
Thick-bedded gray limestones (Keyser, Coeymans, New Scotland).	
SILURIAN	
Cayugan series	
Tonoloway limestone	450
Thin-bedded limestone. Fossils few.	
Wills Creek shale	600
Dove, calcareous, fissile shale, a little limestone. Fossils very scarce. Bloomsburg red member, shale red and green, impure limestone and red sandstone—bottom 50 to 150 feet.	
Bloomsburg red member	
Limestone and shale; fairly fossiliferous.	
Niagaran series	
McKenzie limestone	275 ±
Clinton group	800
Mainly greenish shale weathering purplish. Some sandstone. Thin but workable iron ore beds. Rather fossiliferous.	
Keefer sandstone	
Marklesburg ore	
Frankstown ore	
Block ore	

Medinan series	
Tuscarora quartzite	400
Thick-bedded white quartzite. Extensively used for silica brick. Called ganister.	
Juniata group	850
Red lumpy shale or mudrock, red and greenish gray sandstone. Some finely cross laminated. No fossils.	
Oswego sandstone	800
Medium thick-bedded gray sandstone. Some fine cross laminated. No fossils. Bald Eagle sandstone of Grabau. Oneida conglomerate of Pennsylvania Second Geological Survey.	
ORDOVICIAN	
Upper Ordovician	
Reedsville shale	1000
Thick, dark, rusty weathering, sandstone at top. Maysville age. Shale with thin limestone layers in upper half. Eden age.	
Middle Ordovician	
Trenton limestone	320
Thin-bedded black limestone weathering with a gray film on surface. Sparsely fossiliferous.	
Rodman limestone	30
Dark crystalline limestone weathering with a rough granulated surface; very characteristic and persistent. Fossiliferous. Upper Black River.	
Lowville limestone	180
Dark, thick-bedded, pure limestone, glassy to fine-grained. Extensively quarried for flux. Lower Black River.	
CANADIAN	
Carlim limestone	180
Dark, fine-grained limestone, extensively quarried for flux. Fossils scarce except in Lemont argillaceous limestone member. Lemont member impure, not quarried.	
Lemont limestone	
Beekmantown series	
Bellefonte dolomite	1000
Thick-bedded dolomite yielding much dense chert. Fossils scarce.	
Axemann limestone	100
Thin-bedded blue limestone with dolomite layers. Fossils.	
Nittany dolomite	1000
Thick-bedded, cherty dolomite. Fossils, but not abundant.	
Ozark series	
Larke dolomite	250
Thick-bedded, coarse, steely blue dolomite.	
Mines dolomite	250
Cherty dolomite, oolitic, yields much oolitic and platy scoriaceous chert. *Cryptozoon*, 2 species, common.	
Gatesburg formation	1750
Thick-bedded, steely blue, coarsely crystalline, dolomite with many interbedded quartzite layers up to 10 feet thick. Surface deeply covered with sand and strewn with quartzite boulders. Considerable silicified oolite. *Ore Hill limestone* member, thin-bedded, blue limestone.	
CAMBRIAN	
Elbrook group	
Warrior limestone	250
Thick and thin-bedded, blue limestone with thin siliceous shaly layers or partings. A few thin quartzite layers and an occasional bed of limestone full of large well-rounded quartz grains. Some oolite. *Cryptozoon* common.	
Pleasant Hill limestone	600
Thick-bedded limestone at top. fossils. Argillaceous thin-bedded limestone at bottom weathering to shale.	
Waynesboro formation	250 ±
Sandstone, conglomerate and red and greenish shale.	

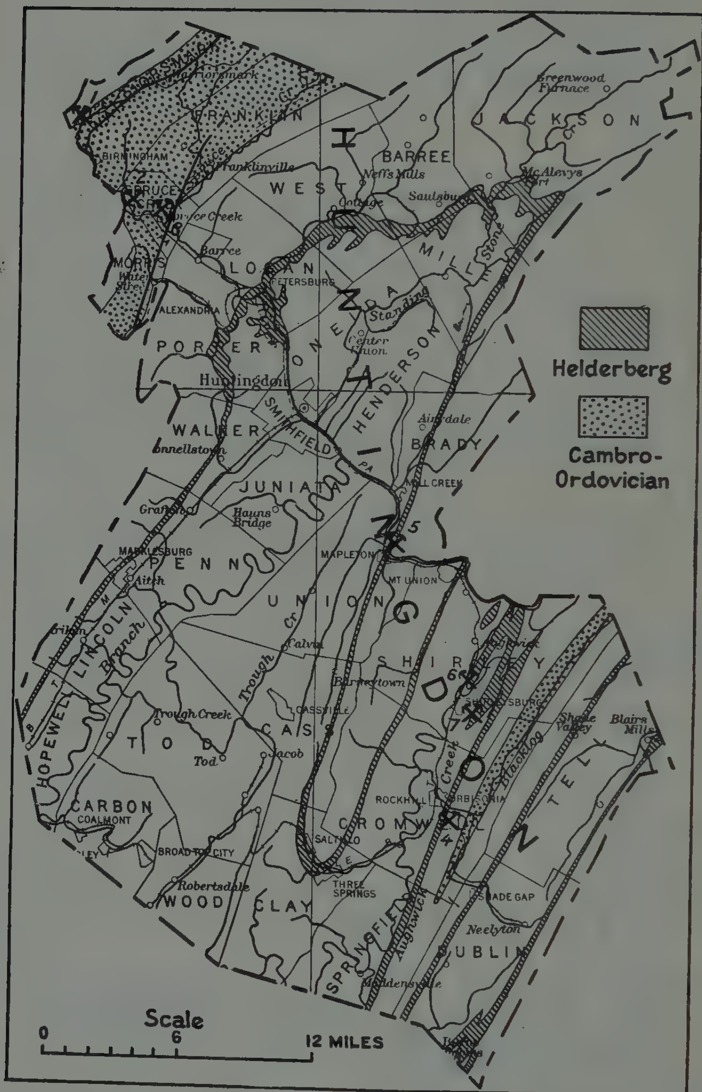

Fig. 16. Limestone areas in Huntingdon County.

1. Tyrone Lime and Stone Co
2. American Lime and Stone Co.
3. Spruce Creek Dolomite and Limestone Co.
4. Grove quarry
5. Mapleton Limestone Co.
6. Shirley Township quarry
7. McGanley quarry.

In the above section it will be noted that limestones and dolomites are present in the Cambrian, Ordovician, Silurian, Devonian, and Mississippian systems. In view of the fact that detailed stratigraphic investigations have not been made generally throughout the county, it is not possible to discuss each limestone formation separately. Instead, the limestones will be discussed under the following divisions: Cambro-Ordovician, Helderberg (including the Tonoloway), other Silurian and Devonian limestones, and Mississippian.

CAMBRO-ORDOVICIAN LIMESTONES

The largest area of Cambro-Ordovician limestones of Huntingdon County is that forming the southwestern end of Nittany Valley, lying between Tussey and Bald Eagle mountains and constituting almost the whole of Warriors Mark, and Franklin townships. Smaller areas are those of Cove Valley or the north end of Morrison's Cove in Morris Township, the southwestern end of Kishicoquillas Valley in Brady Township, and the narrow Black Log Valley between Black Log and Shade mountains in the southeastern part of the county.

The most valuable limestones of the Cambro-Ordovician are the uppermost strata constituting the Carlim, Lowville, Rodman, and Trenton formations. These limestones are, in general, low in both silica and magnesia and consequently adapted to a wider variety of uses than the underlying beds. For crushed stone and building purposes the dolomitic and siliceous beds are equally satisfactory or even better in some instances. Practically every large operation of the region confines its quarrying to the strata above the Bellefonte dolomite.

The anticlinal structure brings the stone of good quality at the sides of the valleys where the strata dip beneath the shales and sandstones of the ridges. The only exceptions to this rule are where the strata have been broken and displaced by faults or where a subordinate syncline (downward fold) brings the upper beds down in the center of the valley. An example of this latter type of structure is seen in the quarry at Union Furnace in the Little Juniata River valley where the upper limestone beds are present about midway of the broad limestone valley through which the stream has cut its course.

The two large active limestone operations of Huntingdon County are those of the Tyrone Lime and Stone Co. and the American Lime and Stone Co. (The Warner Co.)

The plant of the Tyrone Lime and Stone Co., Stover quarry, is located about 1½ miles due east of Tyrone, on the lower slope of Bald Eagle Mountain. This is a large and well equipped quarry that has been operating for a number of years. The capacity of the plant is given as 200,000 tons of crushed limestone, 20,000 tons of agricultural ground limestone, 5,000 tons of pulverized limestone filler, 10,000 tons of pulverized limestone rock dust and 20,000 tons of cupola flux. The production is naturally less except during specially favorable years.

There are 32 tracks running to the quarry face. The rock is quarried by drilling holes into the footwall against the dip and shooting out the base, permitting the upper stone to slide down. This method requires considerable secondary shooting. The stone is loaded by hand. The overburden is slight and no stripping is done.

The grinding and pulverizing plant is well equipped so that practically any requirements can be met. The manager reports that mate-

rial can be furnished in which 99 per cent passes through a 325-mesh screen. Some material that is carried in the return air in the cyclone tank at the top of the mill is said to be minus 700-mesh in size. This has been mixed with the other pulverized material but a market for this product alone is sought. Some of the screenings from the crushed rock is sold to the farmers for agricultural use without further reduction and sizing.

The strata worked belong to the Carlim, Lowville, Rodman, and part of the Trenton. The Lowville (Bellefonte ledge) seems to be present and to be from 18 to 24 feet in thickness. The strata dip steeply to the east at angles of 75° to 80°. They are slightly overturned as they should normally dip westward beneath the Reedsville shales.

A number of small faults are observable in the quarry and the rock generally has been greatly shattered. Many of the cracks have been filled with calcite veins. A few small openings contain cave travertine (stalagmites and stalactites).

A careful survey of the ledges, numbered from west to east, was made in 1917 and is summarized in the following table. The thickness and compositions have been taken from a drawing on which the results were plotted.

Stover quarry of Tyrone Lime and Stone Co.

No. of Ledge	Thickness in feet	Percentage of SiO_2	No. of Ledge	Thickness in feet	Percentage of SiO_2	No. of Ledge	Thickness in feet	Percentage of SiO_2
1	10	9.2	18	14½	1.7	33	6	1.1
2	8½	3.4	19	5	6.85	34	7	2.3
3	10½	2.3	20	4	2.8	35	3	2.2
4	17	5.7	21	8	2.3	36	1½	5.5
5	11	3.0	21a	7½	3.03	37	2½	6.2
6	10	4.0	22	6½	2.55	38	4	4.0
7	12	3.7	23	5	3.4	39	8	4.6
8	10½	2.95	24	11	1.5	40	8	1.15
9	11	1.8	25	9	1.2	41	12	2.15
10	9½	1.2	26	8	2.02	42	10	2.15
11	8	3.0	27	7	12.5	43	7½	2.15
12	4½	4.1	27a	4	19.5	44	1½	3.4
13	7½	2.7	28	2	3.7	45	4	0.7
14	16	4.2	29	6	2.8	46	4	1.1
15	6½	4.05	30	8	6.45	47	5	11.1
16	4½	6.5	31	8	3.6			
17	10½	2.3	32	5	1.6		370 feet	

Average analyses of Stover quarry

	1	2
$CaCO_3$	93.09	93.84
$MgCO_3$	2.76	2.50
$Al_2O_3+Fe_2O_3$	.61	.58
SiO_2	3.54	2.98

1. Mean average for entire quarry.
2. Mean average with exception of Nos. 1, 27, 27a and 47.

At Union Furnace the American Lime and Stone Co. operates three quarries. The beds exposed in the vicinity form a syncline. Quarries 1 and 2 are working the upper strata—Rodman, Lowville, and Carlim—and quarry No. 3 is opened in the underlying Beekmantown.

Nos. 1 and 2 formerly furnished stone for lime and for flux mainly, although some interbedded strata are high in silica and valuable only for concrete or ballast. The stone averages less than 3 per cent SiO_2. The lime made was used for agricultural purposes. The Bellefonte ledge is present in the quarry and, if worked by itself, would yield a chemical lime. The stone from quarry No. 3 is too impure to be satisfactory either for lime or flux and has always been worked solely for crushed stone.

In 1929 only crushed stone was being produced as the fluxing trade seems to be gone. Only Quarry No. 2 was operating at the time visited. The annual capacity of the entire plant is given as 500,000 tons of crushed stone.

These quarries were surveyed and sampled under the direction of J. I. Schlegel, general superintendent, in December, 1917, and February, 1919. The dip of the beds in quarry No. 1 is 70°W. and in quarries Nos. 2 and 3, 40-45°E. Quarrying faces range up to 175 feet high.

The following tables show the thickness and composition of the different beds:

Analyses of Cambro-Ordovician limestone in American Lime and Stone Co. quarry No. 1, Union Furnace, Huntingdon County

(M. M. Morris, Jr., analyst)

	Sample Numbers									
	1	2	3	4	5	6	7	8	9	10
Ft. thick	20	23	80	15	12	13	12	42	24	54
$CaCO_3$	94.23	92.33	90.09	68.83	85.72	78.10	61.72	90.68	90.80	79.75
$MgCO_3$	2.69	1.75	1.41	5.89	3.10	9.38	28.44	4.76	4.76	5.55
SiO_2	2.54	5.16	8.00	24.24	10.48	11.90	8.80	4.06	3.90	13.20
$Al_2O_3+Fe_2O_3$	0.54	0.76	0.50	1.14	0.70	0.62	1.04	0.50	0.54	1.50

	Sample Numbers								
	11	12	13	14	15	16	17	18	19
Ft. thick	24	12	30	80	80	60	45	27	40
$CaCO_3$	81.14	66.30	70.92	93.98	96.14	91.44	90.93	81.28	86.36
$MgCO_3$	4.56	26.20	13.60	2.78	2.40	4.14	2.57	3.68	5.00
SiO_2	13.50	6.80	14.28	3.00	1.26	4.00	5.86	13.72	8.00
$Al_2O_3+Fe_2O_3$	0.80	0.70	1.28	0.24	0.20	0.42	0.64	1.32	0.64

Analyses of Cambro-Ordovician limestone in American Lime and Stone Co. quarry No. 2, Union Furnace, Huntingdon County

	Sample Numbers							
	1	2	3	4	5	6	7	8
Ft. thick	30	45	50	75	30	20	28	18
$CaCO_3$	91.69	86.74	93.60	90.42	89.66	91.18	64.77	76.45
$MgCO_3$	2.37	8.38	3.60	2.78	7.82	4.92	10.33	7.81
SiO_2	5.26	4.36	2.50	6.24	2.20	3.50	23.54	14.20
$Al_2O_3+Fe_2O_3$	0.68	0.52	0.30	0.56	0.32	0.40	1.36	1.54

	Sample Numbers				
	9	10	11	12	13
Ft. thick	10	16	24	12	18
$CaCO_3$	91.70	92.45	88.26	77.47	59.05
$MgCO_3$	3.96	3.85	7.08	12.99	25.65
SiO_2	3.94	3.40	3.50	8.94	14.20
$Al_2O_3+Fe_2O_3$	0.64	0.30	1.16	0.60	1.10

Analyses of Cambro-Ordovician limestone in American Lime and Stone Co. quarry No. 3, Huntingdon County

(M. M. Morris, Jr., analyst)

	1	2	3	4	5	6
Ft. thick	30	15	15	24	8	50
$CaCO_3$	51.58	53.21	54.97	54.22	50.32	54.47
$MgCO_3$	42.76	40.43	40.87	40.68	36.38	40.28
SiO_2	4.96	5.80	3.76	4.70	12.70	4.70
$Al_2O_3+Fe_2O_3$ ...	0.70	0.56	0.40	0.40	0.60	0.55

The same beds outcrop just west of Water Street. Samples were collected here and analyzed by the Cambria Steel Co. The extreme ranges as shown in the following table probably are explained by some samples being taken from the underlying Beekmantown strata.

Analyses of Cambro-Ordovician limestone west of Water Street

	1a	1b
$CaCO_3$	50.37 to 96.07	78.11
$MgCO_3$	1.47 to 39.41	14.51
SiO_2	1.00 to 9.70	4.30
$Al_2O_3+Fe_2O_3$	0.58 to 3.46	2.13
S	0.02 to 0.27	0.09
P	0.004 to 0.024	0.009

1. Myerly farm just west of Water Street. a. Range of 31 samples; b. Average of 31 samples. Analyzed by Cambria Steel Co.

A number of abandoned small quarries elsewhere in Warriors Mark, Franklin, Spruce Creek, and Morris townships were formerly worked for agricultural lime but in recent years some have furnished some road metal for local use. Several of these are in the vicinity of Franklinville. It is there that Indian Cave is located. This rather extensive cave has been developed by solution of portions of the Upper Ordovician strata.

In 1925 The Spruce Creek Dolomite and Limestone Co. opened a quarry about 500 feet northwest of the station at Spruce Creek and in 1927 opened a second quarry about half a mile northeast of the station. The first quarry is about 100 feet in length, about 50 feet in width and extending eastward into the hill. The second quarry is small and located rather high up on the hillside. The average strike is about N60°E. with a dip of 35°SE.

Average analyses from quarries of Spruce Creek Dolomite and Limestone Co.

	First quarry	*Second quarry*
$CaCO_3$	51.11	51.46
$MgCO_3$	42.09	42.34
$Al_2O_3+Fe_2O_3$	1.63	1.27
SiO_2	4.29	4.13

The southwestern end of Kishacoquillas Valley, constituting a part of Brady Township, is floored with Cambro-Ordovician limestones. These are exposed along the highway and in fields nearby. No recently

worked quarries were observed in 1929, but as in former years, although to a lesser extent, the farmers occasionally dig some limestone and burn it in open heaps for farm use. Wood is used as the fuel.

In Black Log Valley only one quarry, so far as known, has been operated recently. This is the Grove quarry, about 2 miles southeast of Orbisonia. There is some fair fluxing stone here that was used formerly in the Orbisonia furnace. It has since been worked for stone for roads in the southeastern part of Huntingdon County. There are several different kinds of stone ranging from low to high magnesian. Most of the stone is dark blue but weathers to a chalky white. Some layers contain rosettes of chalcedony. The beds vary in thickness from 3 inches to 2 feet. The beds show considerable variation in dip and strike but average about 45° dip to the west. The quarry face is about 80 feet in height. A narrow gauge railroad from Mt. Union runs close to the quarry. This quarry has been operated recently by the Mapleton Limestone Company, of Huntingdon, for road metal.

At one time the quarry was sampled by the Cambria Steel Co.

Analysis of stone of Grove quarry

	1a	1b
$CaCO_3$	50.82 to 94.21	81.71
$MgCO_3$	2.13 to 27.60	11.64
SiO_2	1.78 to 16.80	3.88
$Al_2O_3 + Fe_2O_3$ ...	0.54 to 3.80	1.39
S	0.03 to 0.32	0.115
P	0.006 to 0.023	0.010

1. Grove quarry in Black Log Valley, 2 miles southeast of Orbisonia. a. Range of samples; b. Average. Analyzed by Cambria Steel Co.

In general one may say that an abundance of good limestone for flux, for agricultural lime, and in a few places for chemical lime, outcrops near the margins of the Cambro-Ordovician limestone valleys of Huntingdon County, and elsewhere siliceous dolomites that are suitable for crushed stone and for rough building.

HELDERBERG LIMESTONES

The outcrop of the Helderberg (including Tonoloway) limestones loops back and forth across Huntingdon County in six narrow bands that extend nearly or quite across the county in a northeast-southwest direction. Almost everywhere the limestone helps to form narrow deep valleys bordered by high ridges of resistant sandstones.

As in other districts these limestones have been quarried mainly for agricultural lime although plastering lime, stone for ballast and for flux have been obtained in many places. There is much good stone but care must be taken in opening a quarry because of the large amount of interbedded shaly material.

Reeside (3, pp. 209-211) has given the following detailed section near Mapleton. Names of fossils obtained in each bed have been omitted.

Section in Mapleton Limestone Co. quarry

	Thickness in feet
Helderberg limestone (Keyser limestone member):	
Concealed by talus, quarry waste, etc. Much of the talus of the upper part is ash-colored shale.	
Limestone, light gray; banded on weathered surfaces; fresh surface dark gray, fine grained, not banded; conchoidal fracture; 3-inch courses separated by shale	9.0
Limestone, like unit above but not in courses separated by shale; fairly massive	4.8
Shale, calcareous, weathered, yellow	.9
Limestone, very light gray, compact, fine grained; dark on fresh surface; faintly banded	2.8
Limestone, composed entirely of *stromatoporoids*	.9
Shale, weathered yellow	.8
Limestone, massive, light gray; composed of *stromatoporoids*	3.0
Limestone nodules, large, in shale matrix	.8
Limestone, rather platy, shaly dark gray	4.3
Limestone, dark gray, conchoidal, impure, fine grained; in 2 to 12 inch courses, separated generally by thin shale laminae	19.1
Shale, calcareous, containing large nodules (diameter 5-6 inches) of limestone and one or two beds of fine grained conchoidal blue limestone	4.3
Limestone, rather shaly, dark gray; single bed	1.6
Limestone, massive, impure, gray; nodular character indistinct; weathers thin bedded at top of quarry	3.1
Limestone, massive, impure, nodular	1.3
Shale, weathered, yellow	.5
Limestone, impure, nodular, dark gray, somewhat crystalline	3.4
Limestone, impure, dark gray; many cleavage faces of calcite show, giving it a coarse grain; very massive unit; shows indistinct nodular structure	5.6
Limestone, much like unit above but does not show the nodular structure	8.8
Limestone, dark, much weathered in places, massive	3.9
Limestone, pure bluish crystalline layers alternating with shaly dark-gray impure layers; the whole makes a massive unit. Bryozoa throughout	5.0
Limestone, light gray, fine grained, conchoidal fracture	2.0
Limestone, massive, coarsely crystalline, bluish; many small chert nodules	2.4
Limestone, blue gray, coarse, crystalline, pure, thin bedded (2 to 6 inches)	1.1
Limestone, shaly, impure, "Bastard"; weathers light gray and yellow; finely nodular	9.6
Limestone, bluish gray, crystalline, single bed, fairly pure	2.8
Limestone, very impure, earthy, dark gray; shaly fracture	1.5
Shale, fissile, calcareous; weathers a ferruginous brown; has some nodules near top	1.0
Limestone, impure, nodular, dark, single bed	2.0
Limestone, fairly pure, blue, crystalline; nodular character lacking on fresh surfaces and very indistinct on weathered surfaces; thin bedded (2 to 4 inches); a few 2-inch chert nodules scattered near top	5.6
Limestone, nodular, relatively impure, rather coarse grained and with considerable, inter-laminated shale; would be classed as a "Bastard" limestone, but it is purer than the unit beneath	2.4
Limestone, shaly, very nodular, "Bastard", light gray and brown on weathered surfaces	3.5
Limestone, coarsely crystalline, light gray, very pure (98 per cent $CaCO_3$) extremely massive and crinoidal	29.8
Limestone, thin bedded (2 to 3 inches), dark gray, fine grained, distinctly nodular	1.7
Limestone, somewhat nodular but yet massive, dark gray, fine grained	3.8
	153.1
Tonoloway limestone:	
Limestone, medium bedded (4 to 12 inches), pure, dark, gray, not banded; shale between the courses	6.8
Limestone, thin bedded (3 to 6 inches), pure, dark gray, fine grained; banded and light gray on weathered surfaces	2.8
Shale, calcareous	.2
Limestone, massive, dark gray, fine grained, pure; conchoidal fracture. In places shows a 1-inch bedding	3.8
Limestone, light gray, in 3-inch courses with shale between	1.8
Limestone, massive bed, very light gray, fine grained; conchoidal fracture. In this unit there has been dissolved out a good-sized cave reaching down to an unknown depth. The limestone seems very pure and has small scattered masses of crystalline calcite	4.0
Limestone, banded, thin bedded, (2 inches) but not fissile, light gray, pure	5.5
Travertine	.5
Limestone, banded, thin bedded, light gray	3.6

Tonoloway limestone—Continued.

	Thickness in feet
Limestone, very platy, fissile; weathered surfaces have a faint greenish tinge	2.6
Limestone, rather irregular, heavy bed, fine grained, light gray, pure	1.2
Limestone, very platy, fissile, light gray, fine grained; seems fairly pure	3.4
Limestone, dark gray, with a 4-inch layer of chert at center	1.3
Limestone, massive, finely (1-inch) but distinctly nodular, dark gray, impure. Corals	3.0
Limestone, massive, fairly pure, blue gray	3.6
Limestone, fissile, platy, dark gray; layer of chert	5.2
Limestone, fairly solid, banded, dark gray, fine grained	8.9
Limestone, fissile, shaly, impure; drab on fresh surface	5.6
Limestone, fairly pure, knotty, light gray, fine grained	1.5
Limestone, fissile, weathered, brown and gray, fine grained, impure	12.4
Concealed	5.9
Shale, weathered, calcareous, gray to brown	7.4
Shale, poorly exposed, weathered	4.0
Limestone, fissile, impure, gray	5.5
Limestone, platy, gray; looks much purer than unit above or below	1.0
Limestone, fissile, impure, weathered brown	1.0
Concealed	3.8
Limestone, thin bedded (4 to 6 inches), impure light gray	5.0
Shale, calcareous, gray, and limestone, gray to brown, weathered, fine grained; alternating layers of each about 3 inches thick	9.4
Shale, fissile, ash-colored, calcareous	5.5
	126.2

The Mapleton quarry is a large one extending along the hillside for a distance of 500 to 600 feet. The beds dip steeply and are almost parallel to the highway. Most of the strata contain many fossils. Reeside in his complete section gives the names of many of these. The quarry was originally worked to obtain stone for lime burning but more recently for crushed stone. The annual capacity is given as 60,000 tons of crushed stone.

The Helderberg limestones have been quarried at one time or another in Hopewell, Lincoln, Penn, Walker, Logan, Oneida, Brady, Cromwell, Shirley and probably other townships but in every case on a small scale, mainly to obtain stone for flux or for agricultural lime.

In Hopewell Township near the Bedford County line the Helderberg limestones were formerly quarried for flux for a blast furnace one mile to the east. There were 30 to 40 feet of good limestone in the quarry. They were quarried north of Entriken for lime. Only about 30 feet was pure enough to be used. Other beds were too shaly and too high in magnesia.

White (2, p. 125) gives the following section and analyses of specimens in a quarry near Grafton.

Section of Helderberg limestone quarry near Grafton

		Feet
1.	Top layers of gray crystalline limestone	10
2.	Blue limestone	10
3.	Cherty ("nigger head") limestone	2
4.	Ironstone	4
5.	Gray limestone	5
6.	Blackish limestone	7

Analyses of samples from various layers in quarry near Grafton

	Upper 1	*Lower 1*	*4*	*5*	*6*
$CaCO_3$	95.536	98.035	94.642	95.446	93.035
$MgCO_3$	1.589	.908	2.800	1.135	1.816
SiO_2	1.851	.420	1.730	2.350	3.480
$Al_2O_3 + Fe_2O_3$	.490	.410	.370	.520	.730
P	.011	.011	.006	.006	.006

Near McConnellstown the Helderberg limestones have long been quarried for lime. (2, p. 200) East of Petersburg along Juniata River these limestones have been extensively quarried and have furnished much stone for ballast and some that has been used as flux in iron furnaces.

In the vicinity of Mapleton there has been extensive quarrying of the Helderberg limestones. The material has been burned for agricultural lime and used for roads. It contains on an average about 9 per cent SiO_2.

In a quarry near Mt. Union the Helderberg limestone has furnished stone for lime. In the upper part of the quarry good stone is interbedded with cherty layers. The lower part of the quarry contains 43 feet of massive, dark-colored, tough limestone. Seven samples from this layer averaged 3.4 per cent SiO_2.

Near Shirleysburg several quarries have been worked. The Township has worked one about one mile north of Shirleysburg and has another one under lease half a mile east of Aughwick. The rock is hard, some beds gnarly, thickness of beds from 3 to 16 inches. Stone was formerly burned but now the product is entirely crushed stone for the roads. A Mr. McGanley has a small quarry about half a mile southeast of Shirleysburg where both lime and crushed stone are produced. In an old quarry between Orbisonia and Black Log Mountain, where lime was formerly burned, there is an exposure of cherty limestone.

OTHER DEVONIAN AND SILURIAN LIMESTONES

In addition to the limestones described above there are two other limestone horizons represented in Huntingdon County that at present are of little economic importance, but in former years when transportation facilities were poor and iron furnaces numerous, were utilized in several places. The more important of the two is the one called McKenzie limestone by Butts but originally given the name of Barree (or Barre) limestone by White. These were not investigated by the writer. White (2, p. 224) describes an occurrence of these limestones near Barree as follows:

"The rocks rise rapidly bringing up the Barre limestone in the field just above the furnace where it has long been quarried for flux. Only 6′ or 8′ (the upper half), of the limestone layers are used. It is a bluish-gray rock somewhat crystalline, and much streaked with calcite. Its composition as shown by Mr. McCreath's analysis being: Carbonate of lime $CaCO_3$ 89.911, Carbonate of magnesia $MgCO_3$ 2.028, Oxide of lime and alumina $Al_2O_3+Fe_2O_3$ 1.790, Phosphorus P .014, Siliceous matter SiO_2 5.660.

"As analyzed by the late D. J. Morley, chemist for the Cambria Iron Company, the upper portion of the bed was shown to contain: Carbonate of lime, 96.000; a strong trace of phosphorus; sulphur, 0.750; and the lower portion: Carbonate of lime, 91.000; phosphorus, a trace; and sulphur, 0.190."

White gives another description of these limestones as they occur in Jackson Township (2, p. 246) as follows.

"......the dark blue layers of *Barree limestone* (above the Ore sandstone) have been quarried by Mr. John Barr. They yield, upon

burning, a dark, strong lime, which answers very well for agricultural purposes.

"The following analysis of specimens from Mr. Barr's quarries was made in the laboratory of the Survey at Harrisburg:

Analysis of John Barr's limestone

$CaCO_3$	88.687
$MgCO_3$	1.850
$Al_2O_3 + Fe_2O_3$	1.439
S	.164
P	.004
Insoluble residue	8.230"

White has also described some "mostly flaggy, greenish gray and impure" limestones in the Marcellus of Huntingdon County. These are not known to have ever been quarried for use.

MISSISSIPPIAN LIMESTONES

White has described a limestone which he observed in Union, Cass, Todd and Carbon townships and designated the Trough Creek limestone. Butts considers this as the equivalent of the Loyalhanna (Siliceous) limestone so well represented in the counties lying to the west of Huntingdon County. The following descriptions are quoted from White's Report on Huntingdon County (2, p. 274-277). He describes its occurrence in Union Township as follows:

"In the valley of Trough creek are some of the finest farms in the country, of rolling, red shale land; the rocks dipping towards the creek 8° or 10° from the northwest, and somewhat steeper from the east. The red shale points out at the forks of the creek, one mile north of Mr. Brenneman's house.

"The limestone, at the base of the red shale series, is of the greatest importance to the agricultural interests of the valley; for, by a liberal use of it on the fields, they may easily be brought into a high state of fertility; whereas if no lime is applied the soil grows gradually poorer and poorer, until the return is so small that farming is unprofitable. The limestone beds could be opened upon at least 20 farms in this township; and yet there are at present only two farms on which it is quarried. It can be easily found at the edge of the red land on the slope of Terrace mountain, where the gray rocks come up. At many points, however, the outcrop is covered by clays, &c. which have been made by the decomposition of the limestone; but the unchanged limestone beds will be found underneath. They were once quarried by Mr. Brenneman half a mile or more north-east from his house, and 2,000 or 3,000 bushels of lime burned, but the quarry is not now used.

"They are quarried now on the land of Mrs. M. Swope, along the road which leads north over Terrace mountain to Haun's bridge. Here 3½′ of limestone rest directly on sandstone. The lowermost layer of the limestone, being quite sandy, is often rejected. The whole is, however, somewhat siliceous, and has a bluish-gray or greenish cast, non-fossiliferous, leaving a blackish, unctuous clay on decomposed surfaces. The stone is hauled from Mrs. Swope's quarry to many farms in the township, the farmers preferring to burn it themselves on their own premises.

"The only other quarry is on the land of Michael and W. D. Boring, 2½ miles southwest from Mrs. Swope's, where the following beds may be seen:

Boring's limestone quarry

1.	Soil and red shale	5′ 0″
2.	Red, sandy, limy beds	4′ 0″
3.	Greenish limestone	3′ to 3′ 6″
4.	Black clay, (decomposed limestone)	3″
5.	Limestone, upper half good, lower half too sandy for burning	1′ 6″

"The limestone is quarried, after stripping off some overlying shales, along the slope of the hill for several hundred feet. The amount of limestone available here before the stripping becomes too heavy is not large; but there are several other places on the same property where it can be easily worked; one of them in the orchard just east from Michael Boring's house; where it crops out in the road for several yards, and the siliceous portion is seen with its blackened fragments along the ground for a much greater distance. It could also be reached by removing some soil and red shale just northeast from the present quarry.

"Mr. McCreath's analysis shows that Boring's limestone consists of 86.607 per cent of carbonate of lime; 1.574 carbonate magnesia; 1.520, oxide iron and alumina; 0.011, phosphorus; a strong trace of manganese; and 9.530 of siliceous matter.

"It was once opened and burned on the land of Henry Baumgardner; 1 mile southwest from Boring's quarry, but nothing has been done there for many years.

"On the east side of the valley, the outcrop of limestone seems to be much more siliceous, and no one in this township has succeeded in burning it. Mr. Lewis Smith made the attempt, but the rock was merely a limy sandstone and choked up the kiln with slag."

In Todd Township, White describes the same limestone as follows (2, pp. 281-283).

"The sandstones appear in the creek (Trough) at the Cass township line, the limestone outcrop running a short distance east of the creek. A little further south the limestone crosses to the west side of the creek; but at the Todd or brick mills, near Todd P. O., it is quarried in a cliff along the east bank of the creek, on Jackson Miller's land, where the following beds show:

Jackson Miller's quarry

Red, limy beds	10′	15½′
Limestone, greenish, impure	½′	
Limestone (quarried) greenish-gray visible	3′	
Limestone, reported (quarried at low water	2′	

"A good deal of stone has been hauled from here by the farmers. The quarry bed underlies the bed of the creek above and below the quarry.

"A bed of red limestone lying a few feet above the red limy beds is not quarried here. The underlying sandstone is seen coming out of the creek on the west bank.

"Below Todd's mills nothing is seen of the limestone until we come to Taylor's road crossing. Taylor's is a mile below the mill. Here on the east bank is a large limestone quarry owned by F. M. Taylor, Jno. Whiting and Eli Keith, where the following beds show:

Taylor's quarry

1.	Red shales		
2.	Red limestone	4′	
3.	Red shales, limy	16′	
4.	Gray limestone	2′ 6″	30′
5.	Red slates	3′	
6.	Limestone, greensh-gray	4′	
7.	Pocono sandstone		

"The red limestone (No. 2) is mined here and highly prized by the farmers. Nos. 4 and 6 are both good limestone and are taken out entirely down to the sandstone which forms a platform for it as smooth and level as a floor.

"Half a mile further down the creek, just below the Methodist church, we see the limestone with the accompanying shales make a vertical cliff 30′ to 40′ high, just below the mouth of a small stream which puts into the creek from the south. Here the beds are:

Heater's quarry

1.	Red limy shale	20′	
2.	Gray limestone	1′	
3.	Red limy shales	5′	
4.	Gray limestone	3′	36′
5.	Red limy shales	4′	
6.	Sandy, greensh-gray limestone	3′	
7.	Pocono sandstone (visible)	5′	

"A large amount of limestone has been quarried here for farm use; bed No. 3 being that on which the most quarrying has been done; it having been mined back under the overhanging cliffs. The red limestone of Taylor's section probably overlies No. 1. The sandstone (No. 7).. just below the quarry, makes a range of cliffs along the stream.

"Trough creek turns at a right angle to the northwest just above Heater's quarry, and keeps on past Paradise furnace to the gap in Terrace mountain; but in doing this it cuts off a strip of the Barrens, leaving the upper Pocono beds on the south side of the creek. This is shown by the fact that the limestone beds cross Sugar creek half a mile above its mouth, at Griffith's saw mill, where the road to Newburg crosses. An abandoned quarry here shows:

Old Sugar creek quarry

1.	Red limy shales	10′	
2.	Reddish-gray limestone	2′	
3.	Red limy, shaly beds	20′	
4.	Gray limestone (once quarried)	1′	48′
5.	Red beds	5′	
6.	Gray limestone, good (once quarried)	3′	
7.	Concealed	7′	
8.	Pocono gray sandstone, massive		

"For two miles towards T. Baker's road-forks sandstone beds are seen cropping out along the road to Newburg.

"At Baker's a low ridge of red shale crosses the road and runs northward for several hundred yards.

"The Trough creek limestone is quarried on the land of Mr. G. W. Baker, at the mouth of Lick run, ¾ mile east of Newburg."

Baker's quarry

1.	Red shales		
2.	Red brecciated limestone (fossiliferous)	5′	33′
3.	Red shales and limy beds	12′	
4.	Limestone, gray	3½′	
5.	Red shales and limy beds	10′	
6.	Gray limestone	2½′	
7.	Pocono sandstone, massive, gray		20′

"Round Top, (2, pp. 285-287) an isolated mountain rising 950′ above Trough Creek, about ¾ mile south of the furnace, lies in the axis of the trough. It is a mound of red shale No. XI, capped with the bottom layers of the Conglomerate No. XII; about 10 acres; with an edge of cliff all round. The following section was made from the summit straight down to Trough creek, ¼ mile above the furnace:

Paradise furnace Round Top section

1.	Bottom rocks of No. XII, massive grayish white sandstone		15′
2.	Concealed		10′
3.	Iron ore of No. XI; pieces scattered over the ground; trial holes along the outcrop		?
4.	Red shales and green sandstones		500′
5.	Brecciated limestones, reddish, impure; visible		2′
6.	Red shales; by barometer 450 thick; add for southwest dip say 50: making say		500′
7.	Limestone red and mottled, massive, impure	25′	39′
8.	Limestone, red, shaly	4′	
9.	Limestone, gray	3′	
10.	Limy beds, red	7′	
11.	Sandstone at level of Trough creek (900 A. T.)		
	Total thickness of No. XI		1051′

"No fossils were seen in limestone bed No. 5; but it may be taken to represent the limestone series between the upper and lower red shales in the gaps of Westmoreland and Fayette counties and West Virginia, described in Reports K2 and K3.

"The lower siliceous limestone at the bottom of No. XI crops out in the cliffs which border the creek above the furnace. The upper red beds (No. 7) are especially massive; they have been quarried and burned by Mr. Patterson. An analysis by Mr. McCreath shows:

Carbonate of lime $CaCO_3$, 51.785; Carbonate of magnesia $MgCO_3$, 1.188; Oxide of iron and alumina, $Al_2O_3+Fe_2O_3$, 3.380; Manganese Mn strong trace; Siliceous matter SiO_2, 42.510; total, 98.863.

The gray limestone, No. 9, was used as a flux at the old Paradise furnace. An analysis by Mr. McCreath showed:

CALCAREOUS MARL

Carbonate of lime $CaCO_3$, 90.992; Carbonate of magnesia $MgCO_3$, 1.059; Oxide of iron and alumina $Al_2O_3+Fe_2O_3$, 0.940; Phosphorus P, 0.013; Manganese Mn strong trace; Siliceous matter SiO_2, 6.094; total, 99.094".

There are several occurrences of calcareous marl deposits in Huntingdon County. They have been described by J. B. R. Dickey (5, pp. 9-10) in Bulletin 76 of this Survey as follows:

"On the farm of Mr. Cummings, ¼ mile east of McAlevys Fort, occurs a deposit of marl along both sides of a small stream. The deposit no doubt originates from a spring which comes in from the side and which is now piped off to supply a farmhouse. The marl extends down the stream for about 100 yards onto the adjoining farm of Mr. Bigelow. When first discovered as exposed in the banks of the stream the deposit was only 2 to 3 feet in depth. In the course of development the depth of the marl farther from the stream increased to 4 or 5 feet. The width of the deposit varies and is not over 150 feet at any point.

"The marl here is yellowish gray in color, inclined to be granular and to contain considerable quantities of rounded, pebbly concretions and large irregular cementations.

"The surface covering is about 6 inches of brown soil and the marl rests on the native limestone and shale. At some points a layer of black, carbonaceous material 2 to 3 inches thick occurs about the middle of the deposit. This is apparently a mucky organic deposit. The lime in the marl varies from 80 per cent for the finer material to 95 per cent for the purer concretions.

"This deposit was discovered by the County Farm Bureau Agent and the Extension Specialist in 1919. Its value was explained to the farmers and several hundred tons have been dug out and applied with good results. Applications are made with a shovel and probably average four tons per acre. The owners have received \$1 to \$1.25 per load, which for the rather coarse and undried marl is rather a high price.

"On the farm of William Bair, 2 miles east of McAlevys Fort, occurs an excellent deposit of very fine textured marl, free from concretions and analyzing, air dry, about 85 to 90 per cent $CaCO_3$. The deposit starts just below a spring and extends along the spring drain for about ¼ mile, with a width seldom over 50 feet. At one point where the stream has eroded a channel, 6 to 8 feet of marl is exposed with very little surface covering. This marl is ashy gray in color and loose and friable in texture. When the value of the deposit was explained to the owner he made several small experimental applications, with good results. Farms in this neighborhood are in need of lime and this marl might be used if the price were reasonable."

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INDIANA COUNTY

The limestones of Indiana County are of minor economic importance although they are present in many places and at a number of geological horizons. When it was the custom for farmers to burn the lime which they used on their farms, limestone was quarried in scores of places along the hillsides where the beds outcrop. Nearly all of these quarries were small as it was not profitable to continue them far into the hillside on account of the increasing thickness of the overburden. This practice of lime burning on a small scale continues but in recent years the operations have been fewer.

At present raw limestone is pulverized for agricultural purposes in a few places and in several localities the open quarries have been extended into mines as the strata have been followed into the hills.

The only operation of any size in the county in recent years is that concerned with the quarrying of the siliceous Loyalhanna limestone for ballast and paving blocks.

General geologic section of Indiana County

	Thickness in Feet
Pennsylvanian:	
Monongahela group	200
Benwood limestone	
Sewickley coal	
Sewickley (Fishpot?) limestone	
Redstone coal	
Pittsburgh sandstone	
Pittsburgh coal	
Conemaugh group	700
Pittsburgh limestone	
Connellsville sandstone	
Morgantown sandstone	
Barton coal	
Barton limestone	
Ames (Crinoidal) limestone	
Saltsburg sandstone	
Gallitzin coal	
Mahoning sandstone	
Mahoning limestone	
Allegheny group	300
Upper Freeport coal	
Upper Freeport limestone	
Bolivar fire clay	
Butler sandstone	
Allegheny group, continued	
Lower Freeport coal	
Lower Freeport limestone	
Upper Kittanning coal	
Johnstown (Cement) limestone	
Middle Kittanning coal	
Lower Kittanning coal	
Vanport (Ferriferous) limestone	
Clarion coal	
Clarion sandstone	
Brookville coal	
Pottsville series	130
Homewood sandstone	
Mercer coal	
Mercer shale	
Connoquenessing sandstone	
Mississippian:	
Mauch Chunk series	200
Loyalhanna limestone	
Pocono series	1100
Burgoon sandstone	
Patton shale	

Distribution of the Geological Formations. The lowest strata in Indiana County belong to the Pocono series. The Pocono, Mauch Chunk, and Pottsville are sparingly developed in the southeastern part of the County and the Monongahela beds cap the tops of only a few hills in the extreme western and southern parts. The Allegheny and Conemaugh groups include nearly all of the exposed strata.

LOYALHANNA LIMESTONE

The Loyalhanna limestone lying just above the Pocono series, outcrops in the southern part of Indiana County in three places. Two

of these are along Conemaugh River where it cuts through Laurel Hill in the southeastern corner of the county and Chestnut Ridge about 3 miles east of Blairsville, and the other where Black Lick Creek cuts through Chestnut Ridge about midway between Heshbon and Black Lick. In each case the bed is brought up in these two pronounced anticlinal folds and exposed only in the narrow gorges cut by the streams.

This limestone is frequently termed the Siliceous limestone because of its high silica content and was designated as the Mountain limestone by the Second Geological Survey of Pennsylvania and included in the base of the Mauch Chunk formation. It ordinarily analyzes about 50 per cent silica and about 25 per cent calcium carbonate. Consequently its value is for other purposes than that for which limestone is ordinarily used. It has been extensively quarried for paving blocks and for railroad ballast. The splitting of the blocks is by hand. The stone for ballast is loaded by steam shovel into cars to be hauled to crusher where it is broken and sized. It could probably be used to advantage for the production of mineral wool.

On the right bank of Conemaugh River about 1 mile east of Strangford a large quarry is being operated by John J. Ryan of Pittsburgh. When visited in 1929 the company was making about 1500 paving blocks daily and was also shipping stone for ballast. The section could not be measured because of the inaccessibility of certain portions but is given by the quarry superintendent, J. F. Noble, as follows:

Section of Loyalhanna limestone at Strangford

	Feet
Shale overburden	25 to 40
Gray calcareous sandstone	20
Dark-colored siliceous limestone	12
Slightly different dark-colored siliceous limestone	6
Blue calcareous sandstone	40
Total thickness limestone	58

Each of the divisions is divided into different beds, most of which are 2 to 3 feet in thickness. However, one bed of the basal blue stone is approximately 20 feet thick. As in all of the other occurrences of the Loyalhanna, crossbedding is a prominent feature although this is not as noticeable in the Ryan quarry as in some of the localities in Westmoreland County. The entire thickness of the Loyalhanna is shot down. The blue stone near the base is better fitted for paving blocks.

So far as known, the Loyalhanna limestone has not been worked in the other two localities in the county where it is exposed. It is similar in character in all these places.

LIMESTONES OF THE ALLEGHENY GROUP

Vanport (Ferriferous) limestone. The Vanport limestone is sparingly developed in Indiana County. This is unfortunate as it is the best quality stone occurring in the county. It is discontinuous, probably due to its non-deposition although it may have been deposited in certain localities and subsequently removed. It may perhaps be

found in a few other places than those described below. Near Richmond it is a high-grade limestone about 5 feet thick that outcrops in several places. An analysis (2, p. 264) of a four-foot bed once quarried half a mile south of Richmond is as follows:

Analysis of Vanport limestone near Richmond

$CaCO_3$	92.857
$MgCO_3$	1.589
$Al_2O_3+Fe_2O_3$	2.030
S	.187
P	.035
Insoluble residue	2.090

West of Smithport along Straight Run a measured thickness of 6 feet has been noted and a 5-foot bed northeast of Smithport along South Branch of Bear Run.

It was recognized only by fragments on the north slope of Yellow Creek along the axis of the Chestnut Ridge anticline. In a drill hole on Ramsey Run, a limestone 8 feet 9 inches in thickness was encountered 175 feet below the Upper Freeport coal and referred to the Vanport.

Altogether the Vanport is of little value in Indiana County on account of its limited development and its thinness.

Johnstown limestone. The Johnstown limestone (cement bed) is developed in several places in Indiana County, mainly as an impure limestone but in certain localities fairly pure. It can be traced along the summit of Chestnut Ridge through Grant and Banks townships. In the Ligonier Basin between Chestnut Ridge and Laurel Hill it is about 2 feet thick along Conemaugh River near Bolivar and Robinson but about 10 feet thick in some places along Black Lick Creek. It was once quarried extensively for agricultural lime in this region. Near Heshbon it contains 5 feet of good stone, once quarried for agricultural lime. Along Richards Run it has also been quarried for lime. There it consists of a somewhat ferruginous layer 1 foot thick underlain by a 4-foot bed of good limestone.

In the bed of Toms Run near Strangford a 7-foot bed of limestone regarded as the Johnstown is described by Platt (2, p. 182) "The limestone is of a dark color, compact and hard; it produces a reddish lime from the large amount of iron contained in it." An analysis of a specimen from this locality is given below (No. 1).

Near Josephine (formerly Bells Mills) Platt (2, p. 190) describes an occurrence of the Johnstown limestone as follows:

Section of Johnstown cement bed, near Josephine

	Ft.	in.
Limestone, good	4	0
Calcareous clay	1	0
Limestone	1	0
Argillaceous limestone	3	0
Limestone, good	2	3
Limestone and clay	4	0
	15	3

"In this section the unusual thickness of the limestone ...... is especially noteworthy. It is finely exposed in the left bank of the Creek just above the bridge. The measures are here dipping sharply to the northwest, and the deposit quickly disappears beneath the stream bed ...... Portions of the deposit yield good fertilizing material, but much of the limestone is greatly intermixed with impurities, and is unfit for agricultural purposes. The specimen selected for analysis was taken from the top bank, and while not especially pure, nevertheless calcines readily and produces a tolerably good lime. The limestone is very firm, of a bluish color, and semi-crystalline." The analysis in full is given below (No. 2).

Analyses of Johnstown limestone from Indiana County

[Anaylses by A. S. McCreath]

	No. 1 (2, p. 182)	*No. 2* (2, p. 190)
$CaCO_3$	82.321	78.768
$MgCO_3$	8.021	2.421
$Al_2O_3 + Fe_2O_3$	2.630	3.540
S	.102	.097
P	.017	.018
Insoluble residue	5.502	13.790

The Johnstown limestone is present in the vicinity of Marion Center. About a mile to the southeast it is 3 feet thick "grayish blue, semi-crystalline, fossiliferous, and yields when calcined tolerably good lime."

Lower Freeport limestone. The Lower Freeport limestone, which lies a short distance below the Lower Freeport coal, has scarcely been recognized in Indiana County. Where present it is decidely impure. Attempts were made to burn it along the lower Brush Creek valley but the stone was burned with difficulty and yielded a reddish-brown lime. It is reported to occur in the hillside above Yellow Creek close to the Green-Pine township line where it is 6 feet thick and consists of a bluish stone with minute fossil shells.

Upper Freeport limestone. The most widespread and persistent limestone of Indiana County is the one which underlies the Upper Freeport coal. In places it lies with a foot or two of the coal but in other sections it is separated by as much as 20 feet of intervening shale. In thickness it ranges from 1 to 10 feet but in most places is about 8 feet. In chemical composition it also shows considerable range due mainly to varying amounts of argillaceous matter intimately mixed with the calcareous content or interbedded with the more calcareous layers. Accordingly the insoluble residue (mainly silica), alumina, and iron oxide are high in some samples and low in others. The magnesium carbonate ranges from 1 to 16 per cent with an average of about 4 or 5 per cent.

It is the Upper Freeport limestone that has been most extensively used throughout the county. It has been quarried in the past in scores of places to obtain small quantities of stone for burning for agricultural lime. This has been its principal use although some layers furnish fairly good stone for foundations or for crushed rock. There

is no likelihood of it ever furnishing stone for any important operations.

The descriptions that follow do not by any means include all of the localities where the Upper Freeport limestone is present. They are presented to give some idea of its general character and distribution.

The Upper Freeport limestone is developed in many places about Marion Center and between there and Little Mahoning Creek. About 1¼ miles southeast of Marion Center there is a ruin of an old brick lime kiln but the slumping of the overlying shales has now concealed the stone in the old quarry. About the same distance southwest of Marion Center a little limestone has been quarried and burned in recent years.

The Upper Freeport limestone is well developed along the valley of Little Mahoning Creek below Smicksburg where it has been dug.

About 1½ miles southwest of Smithport a section of the Upper Freeport limestone was given by Platt (2, pp. 220-221) as follows:

Section of Upper Freeport limestone 1½ miles SW of Smithport

	Ft.	*in.*
1. Cement limestone	2	6
2. Clay		1 to 5
3. Limestone	1	0
4. Clay		½ to 5
5. Limestone	2	6
6. Clay		1 to 3
7. Limestone	3	0
	10	1

Samples from layer 1 and a combined sample of layers 3 and 5 were submitted for analysis and are given as Nos. 1 and 2 in table at close of this section. The upper layer as shown by the analysis was improperly called "cement limestone" as it is not at all suitable for that purpose.

About 1 mile southeast of Richmond where the Upper Freeport limestone is about 3 feet thick a small amount of stone has been quarried in the side of a hill for burning. Due to solution, the bed is missing in places. There has been little activity here in recent years.

Between Deckers Point and Marion Center the Upper Freeport limestone is about 3 feet thick. A sample analyzed by A. S. McCreath (2, p. 228) is given as No. 3 in table on later page.

The Upper Freeport limestone which lies from 1 to 20 feet below the Upper Freeport or E coal is very persistent throughout Canoe and Grant townships. It shows a variable thickness with an average of about 3 feet. The Second Geological Survey reported a thickness of 21 feet 4 inches a short distance south of Juneau but this measurement is questionable. The limestone is of rather poor grade with the magnesium carbonate up to 16 per cent and the iron, alumina, and silica also fairly high in almost every case and unusually high in certain places, due to the shaly character of the rock.

The Upper Freeport limestone from 2 to 6 feet in thickness is found at a number of localities in the central part of the county. This bed is developed to the west and to the northwest of Green-

ville where it has been quarried for agricultural lime. It is a bluish fossiliferous limestone about 6 feet thick. Along the lower course of Brush Creek it has been burned satisfactorily for agricultural lime. Along Two Lick Creek it is fairly pure, about 10 feet thick, and has been quarried and burned.

About 1 mile east of Chambersville the Upper Freeport limestone has been quarried. It is claimed to be 10 feet thick. It contains concretionary masses of calcite. A specimen analyzed by McCreath is given as No. 4 in table on later page.

On the lower course of Yellow Creek the Upper Freeport limestone is separated by an interval of 7 feet with the following section described by Platt (2, pp. 204-205).

Section of Upper Freeport limestone on Yellow Creek

		Ft.	in.
Limestone		3	6
Iron ore	Freeport ore	1	0
Fire clay	Freeport ore	3	6
Iron ore	Freeport ore	1	0
Fire clay		1	6
Limestone		2	0

"The limestone is of a bluish cast, slightly fossiliferous and slakes easily." The specimen from this locality forwarded to Harrisburg for analysis gave the results shown in table No. 5 on a later page.

The Upper Freeport is developed in the vicinity of Dixonville along Dixons Run.

On the South Branch of Plum Creek about a mile below Willet (formerly Five Points) the Upper Freeport limestone outcrops in the bed of the creek. It is rather impure as shown by the analysis No. 6 in the table.

The Upper Freeport ranging in thickness up to 10 feet has been quarried west and northwest of Mitchells Mills. About 1 mile northeast of Taylorville the limestone is found about 28 feet below the Upper Freeport coal and consists of 3 layers separated by shale, aggregating 6 feet in thickness. The limestone is fairly impure. It is present in many places in Pine Township.

A short distance southwest of Strongtown it was quarried at one place for agricultural lime and exposed the following section.

Section of Upper Freeport limestone SW of Strongtown

	Ft.	in.
Bluish limestone	1	0
Clay and shales	1	4
Bluish limestone fossiliferous	4	0

The Upper Freeport limestone lying about 8 feet below the Upper Freeport coal has been recognized in a few places in the vicinity of Elders Ridge. It is about 3 feet thick, and has been burned for agricultural lime. In a small branch of Blacklegs Creek it has been quarried. Near the mouth of Coal Run, 2 miles south of Jacksonville, it is composed of several layers aggregating 6 feet lying 6 feet below the Upper Freeport coal. An analysis by McCreath (2, p. 250) is given as No. 7 in the table.

Near Strangford the Upper Freeport limestone lies about 5 feet below the Upper Freeport coal. It is a little over 3 feet thick, bluish in color and filled with fossil impressions. A specimen from here was analyzed and results given under No. 8 in table.

The Upper Freeport is 4 to 5 feet thick in the vicinity of Saltsburg. An analysis of a sample from the Westmoreland side of the Conemaugh is given in the description of limestones of the county.

Throughout the Ligonier Basin the Upper Freeport limestone is a persistent stratum with an average thickness of about 6 feet. It has been burned for agricultural lime but the lime is of little use for plastering. It is almost everywhere fossiliferous, the fossils being minute univalve shells.

Analyses of Upper Freeport limestones from Indiana County

(A. S. McCreath, analyst)

	1	2	3	4
Carbonate of lime	36.214	58.750	88.232	84.407
Carbonate of magnesia	16.883	16.005	1.371	2.800
Oxide of iron and alumina ..		7.380	1.960	2.120
Carbonate of iron	8.078			
Carbonate of alumina	4.360			
Sulphur	.056	.041	.048	.188
Phosphorus	.056	.085	.017	.018
Insoluble residue	32.790	15.060	8.210	9.150

	5	6	7	8
Carbonate of lime	72.264	84.125	89.821	54.768
Carbonate of magnesia	6.493	5.198	1.801	8.627
Oxide of iron and alumina ..	4.190	3.220	1.700	6.930
Sulphur	.068	.073	.133	.112
Phosphorus	.029	.014	.027	.017
Insoluble residue	14.980	6.021	5.430	27.230

1. A. Gorman's quarry, two miles southwest from Smithport. Upper portion of deposit. Hard and tough, with rough irregular fracture and pearl gray color. Emits a strong argillaceous odor when breathed upon.

2. A. Gorman's quarry, two miles southwest from Smithport. Lower portion of deposit. Hard and tough, with irregular fracture and bluish gray color. Emits a strong argillaceous odor when breathed upon.

3. S. Palmer's quarry, three-quarters of a mile west northwest of Decker's Point. Irregularly seamed with white crystalline carbonate of lime; exceedingly brittle, with rough, irregular fracture and bluish gray color.

4. Groft Brothers' quarry, 1 mile east of Chambersville. Compact, brittle, dark bluish gray, with irregular fracture (3, p. 292).

5. D. R. Griffith's quarry, 1½ miles north northeast from Homer. Compact, brittle; dark bluish gray, with irregular fracture. Emits a strong argillaceous odor when breathed upon (3, p. 292).

6. Rev. S. Brown's quarry, 1½ miles southwest from Five Points. Compact, brittle; sparkles with calcite; bluish gray, with subconchoidal fracture (3, p. 292).

7. S. C. Hazlett's quarry, 2 miles south of Jacksonville. Compact, brittle, bluish gray, with sub-conchoidal fracture.

8. G. Livengood's quarry, 3 miles east southeast from Blairsville. Compact, brittle; bluish gray; with irregular fracture; sparkles with calcite. Specimen more or less stained with iron oxide, emits a strong argillaceous odor when breathed upon.

LIMESTONES OF THE CONEMAUGH GROUP

Here and there throughout the county are discontinuous beds of limestone that are difficult to correlate so that they scarcely warrant separate descriptions. They have been quarried in a few places only and are in general of little value.

About three-fourths mile east of Smicksburg the Smicksburg Lime Company has recently mined and pulverized limestone for agricultural use. The strata worked seem to belong in the Conemaugh group but the particular limestone is not known. At this place limestone is said to have been quarried and burned for 50 years or more, but more recently it has been pulverized and at present the stone is being obtained by following the beds into the side of the hill and mining the material. When visited the mine had been extended about 220 feet under cover. The mining is not done very systematically. Occasional pillars are left and some timber is used.

Section of limestone bed near Smicksburg

	Inches
Sandstone roof	
Compact, bluish-gray limestone, somewhat iron stained	13-16
Shale parting	
Massive, compact bluish gray limestone ..	11-13
Alternating beds of blue shale and limestone; some of the limestone appears as rounded concretionary masses	24-26
Compact thick bed of bluish gray limestone breaking with glassy fracture	42
Shale parting	
Limestone similar to above	17-20
Shale parting	
Gray limestone	14
	10 feet 11 inches

The stone is pulverized to pass through a 16-mesh screen. In 1929 it was sold at the plant for $4.25 per a ton. The production has been as much as 1300 tons a year but is less now.

About a mile east of North Point, limestone has been recently mined in the side of a hill and pulverized for local farm use. The bed worked is about 6 feet thick. At different times many quarries have been opened in the limestones about Smicksburg. Nearly all were for the purpose of securing agricultural lime.

The Conemaugh formation in Canoe Township contains the Mahoning limestone in a few places. Its position is 50 to 70 feet above the Upper Freeport or E coal. It averages about 4 feet in thickness.

A three-foot bed of fossiliferous limestone about 1½ miles southwest of Homer has been referred to the Ames. In Brush Valley about three-fourths mile northwest of Rico a thin limestone, probably the Barton, has been quarried. It lies about 300 feet above the Upper Freeport coal.

The Pittsburgh limestone of the Conemaugh has been recognized near the Armstrong County line and has been quarried north of Elders Ridge for agricultural lime. There it is about 5 feet thick and fairly pure. "It is generally compact, moderately heavy bedded, and brittle. The weathered surface is light colored, but a fresh fracture shows

bluish-gray seamed with bluish-black." (8, p. 5) In the Blairsville region it is separated into three layers, aggregating 5 feet of good stone.

East of Dilltown on Black Lick Creek, Platt (2, p. 103) gives the following section of this limestone.

Section of Pittsburgh limestone east of Dilltown

	Feet
Limestone dark	4
Limestone, impure in layers separated by carbonated slates	3
Impure fireclay	2
Limestone and shales	2

Along Black Lick Creek, in the Ligonier Basin, Platt (2, pp. 77-78) described a 6-8 foot bed of black fossiliferous limestone lying about 225 feet above the Upper Freeport coal. This same bed was noted in other sections. It is probably the Ames limestone, although possibly the Barton. Fossils collected from it or from immediately overlying black shales in several different localities were identified by J. J. Stevenson.

Polyphemopsis peracutus
Astartella concentrica Con.
Bellerophon carbonarius Cox.
Bellerophon percairnatus Con.
Bellerophon montfortianus N. & P.
Lophophyllum proliferum McC.
Pleurotomaria carbonaria N. & P.
Pleurotomaria greyvilliensis N. & P.
Macrocheilus primogenius Con.
Euomphalus subrugosus M. & W.
Schizodus sp.

LIMESTONES OF THE MONONGAHELA GROUP

The strata of the Monongahela group are sparingly developed in the southwestern and southern parts of Indiana County. Limestones have been recognized in only a few places.

The Sewickley limestone, possibly the equivalent of the Fishpot limestone of the Monongahela Valley, has been reported to occur along Conemaugh River in the southwest corner of the county, 10 feet below the Sewickley coal. It is said to be "at least 6 feet thick, composed apparently of good limestone."

The Sewickley limestone, of undetermined thickness, 3 to 4 feet and possibly more, outcrops in the higher hills between Blairsville and Blacklick Creek and has been quarried. It is semi-crystalline, fossiliferous, and brownish in color. A sample from here analyzed by A. S. McCreath (2, p. 159) gave the following results:

Analysis of Sewickley limestone

$CaCO_3$	79.821
$MgCO_3$	3.601
$Al_2O_3 + Fe_2O_3$	3.020
S	.117
P	.018
Insoluble residue	12.160

The Monongahela formation near Elders Ridge contains the Benwood limestone. "It consists of several layers of limestone separated by variable thickness of shales, in all about 25 feet. The limestone is grayish in color, smooth and compact,and non-fossiliferous. It has been burned for fertilizer and found excellent for that use, as it makes

a strong lime and is easy of access. No stripping is required in order to quarry it, because all the limestone lies in the very crown of the highest knolls in the middle of the basin. Where the bed is present, abundant fragments of gray limestone usually are found on the ground." (8, p. 6.)

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The geology of Indiana County was reported upon by the geologists of the First and Second Geological Surveys of the State and since that time portions of the county by the U. S. Geological Survey and by the present Geological Survey of Pennsylvania. The following list includes the most important publications dealing with the geological features of the county. These have been used freely to supplement the author's observations.

First Geological Survey of Pennsylvania:

1. The Geology of Pennsylvania, by Henry Darwin Rogers. Vol. II, particularly pp. 497-499, 538-540, 589-591. Philadelphia, 1858.

Second Geological Survey of Pennsylvania:

2. Report of Progress in Indiana County, by W. G. Platt, Report HHHH, 316 pp., colored geological map. Harrisburg, 1878.

3. Second Report of Progress in the Laboratory of the Survey at Harrisburg, by A. S. McCreath, Report MM, pp. 286-298, Harrisburg, 1879.

U. S. Geological Survey

4. Stratigraphy of the Bituminous Coal Field of Pennsylvania, Ohio and West Virginia, by I. C. White. Bulletin 65, 212 pp., Washington, 1891.

5. Limestones of Southwestern Pennsylvania, by Frederick G. Clapp. Bulletin 249. 52 pp., Washington, 1905.

6. Geologic Atlas of the United States, Indiana Folio, No. 102, by George B. Richardson, 7 pages, maps and sections, Washington, 1904.

7. Geologic Atlas of the United States, Latrobe Folio, No. 110, by Marius R. Campbell, 15 pages, maps and sections, Washington, 1904.

8. Geologic Atlas of the United States, Elders Ridge Folio, No. 123, by Ralph W. Stone, 10 pp. maps and sections, Washington, 1905.

9. Geologic Atlas of the United States, Johnstown Folio, No. 174, by W. C. Phalen, 15 pp., maps and sections. Washington, 1910.

10. Geologic Atlas of the United States, Barnesboro-Patton Folio, No. 189, by M. R. Campbell, F. G. Clapp, and C. Butts, 13 pp., maps and sections, Washington, 1913.

11. Mineral Resources of Johnstown, Pennsylvania, and vicinity, by W. C. Phalen and Lawrence Martin, Bull. 447, 142 pp., Washington, 1911.

Pennsylvania Topographic and Geologic Survey.

12. Atlas of Pennsylvania, No. 65, Punxsutawney Quadrangle, Geology and Mineral Resources, by George H. Ashley, 145 pp., maps. Harrisburg, 1926.

JEFFERSON COUNTY

The limestones of Jefferson County, even though they are all discontinuous, are fairly well distributed throughout the entire region with the exception of the northern townships. Some of them have not been definitely correlated but the following limestone horizons have been recognized.

Conemaugh group	Ames—315 feet above Upper Freeport (E) coal
	Woods Run (Cambridge)—220-240 feet above Upper Freeport (E) coal
	Brush Creek—100-120 feet above Upper Freeport (E) coal
	Mahoning—50-70 feet above Upper Freeport (E) coal
Allegheny group	Upper Freeport—1-20 feet below Upper Freeport (E) coal
	Lower Freeport—1-10 feet below Lower Freeport coal
	Johnstown—between Upper and Middle Kittanning coals
	Vanport—30-50 below Lower Kittanning coal

The thicknesses of the different limestones are extremely variable as indicated in the detailed descriptions, and the variations are rapid. Within a distance of half a mile a 10-foot stratum may gradually thin and entirely disappear. This indicates extremely local conditions of deposition or erosion in part before the formation of the overlying beds. In most cases, the limestones seem to disappear through gradually passing into shales or sandstones by increase in mud and sand during their formation.

The limestones of Jefferson County are of local economic importance only, yet the fact that they have been quarried in scores of places indicates that they have been of considerable value. In the past when the use of agricultural lime was more general and transportation facilities poor, many farmers not only burned the lime needed on their farms but sold some to their neighbors. Although the limestones are still ample, this practice has largely been discontinued. Less agricultural lime is being used and such as is consumed is mainly shipped in from larger operations in other counties. However, there is still some quarrying of limestone within the county. Due to the thinness of the ledges in most places, their discontinuity, and variability in chemical composition, there is little likelihood that they will ever be of more than local value.

In the descriptions that follow, the Vanport is described separately and the others are grouped.

VANPORT LIMESTONE

The Vanport limestone is developed in the southwestern and northeastern portions of Jefferson County. The horizon at which it should occur extends entirely across the county, but apparently there is a band where the limestone is not present or is so poorly developed that it has not positively been recognized. The townships where it is definitely present are the following: Porter, Ringgold, Perry, Oliver, McCalmont, Clover, Rose, Knox, Washington, Warsaw, Snyder, and Polk. The band where it appears to be almost, if not entirely, undeveloped, includes the following townships: Eldred, Union, Pine Creek, northeastern part of Knox, southern part of Warsaw, and Winslow.

The geologic map of the county published by the Second Geological Survey did not distinguish between the actual outcrops and the horizon where it should occur. It is probable that detailed work will extend the limits in some places and eliminate certain areas in other sections.

The Vanport in Jefferson County, where exposed and recognized, varies from 3 to 10 feet but averages about 5 feet. Where absent it seems to be replaced by sandstone. It is generally distinguishable by its extremely fossiliferous character in which crinoid stems and fragmental brachiopod remains predominate. It breaks with a rough fracture, is generally in massive beds, and in most places has the iron-ore band, commonly called Buhrstone ore, immediately overlying. This iron ore layer is of no economic importance in this region.

There have never been any important operations in the Vanport limestone of this county, nor does it seem likely that there will be. The stone, nevertheless, has been quarried in many sections to furnish stone for burning, mainly for agricultural lime, and less commonly for building stone. The stone is of good quality as shown by two analyses on later pages. It has been used to a limited extent for crushed stone. It is also well adapted for pulverized limestone for agricultural use or for mine dusting, although no instance is known to the writer where it has been so utilized in this county.

The Vanport limestone outcrops in the valleys of Pine Run and the Middle Branch of Pine Run in the vicinity of Dora, Porter and Ringgold townships and again in the bottom of Pine Run a short distance east of the Armstrong-Jefferson county line. Between the mouths of Caylor Run and Painted Run along Pine Run this limestone lies below the surface, carried down by a pronounced synclinal fold. It has been quarried along the Middle Branch of Pine Run where a thickness of 5 feet has been exposed. It is characteristically well-filled with crinoid stems.

The Vanport appears in a small tributary stream of Big Run in the northwest corner of Perry Township where it has been quarried for lime.

The Vanport limestone is exposed in Ringgold Township along Big Run and its tributaries. On the right bank of Big Run, a short distance southeast of Worthville, it has been quarried at one place for fertilizing purposes. "The stratum (2, pp. 47-48) is about 4 feet thick in one compact layer, of a light grayish color, brittle, of good quality and fossiliferous, displaying in this respect its characteristic encrinitic stems." (For analysis, see table, page 442, analysis 13.)

The Vanport is also present in the valley of Little Sandy Run, south of Langville, and in the valleys of Cherry Run and Nolf (formerly called Milliron) Run, southeast of North Freedom.

The Vanport limestone is well developed in the valleys of Big Run and Sandy Run in Oliver Township. In the valley of Big Run (2, p. 54) "It is easily recognized from its characteristic fossils which it here carries in abundant profusion. Moreover, though reduced in thickness it here retains to a great extent those lithological characteristics which distinguish it throughout those western counties where it attains its maximum of development. It is of a light greyish color, mottled with iron; it has a rough uneven surface at the fresh fracture; and on its weathered face it presents that peculiarly rugged appearance by which those familiar with it readily distinguish it. Throughout the Big Run valley it is in excellent conditon for use as quarry lime, and splitting

easily it can be cheaply raised. At the upper end of the valley it is not exposed.'' It has been quarried in small quantities along the south bank of the run for fertilizing purposes. (For analysis, see table on page 442, analysis 12.)

It also outcrops south and southeast of Sprankle Mills. At one place where it was quarried, it contained from 5 to 7 feet of good stone, dark in color and containing numerous fossils.

The iron band so commonly present immediately above the limestone seems to be absent throughout the valley of Big Run.

The Vanport appears to be continuous throughout the valley of Little Sandy Creek throughout Oliver Township from the Ringgold-Oliver line, where it appears in the stream bed to and even beyond the township line into McCalmont and Knox townships.

In places it is brought rather high in the valley slopes by an anticlinal fold. It varies from 3½ to 4 feet in thickness and has been locally quarried in a few places. It is of good quality. The iron ore layer, 7 inches in thickness, was observed at one place.

In Beaver Township the Vanport has been traced almost continuously in the headwaters of Reitz, Tarkita, and Beaver runs near the upland divides. North of Beaver Run it also appears in others high up on the hill slopes. It has a thickness of 4½ to 5 feet and is of good quality. Quarries for lime burning in the hillside have been operated locally on a small scale in many places.

Throughout Clover Township the Vanport limestone is widespread. Ranging from 4 to 6 feet in thickness, the outcrops in the valley of Redbank Creek have been worked in many localities. In most places it lies high in the hillsides, from 80 to 150 feet above the stream. There are scores of places where it has been worked for lime burning on a small scale and in recent years for crushed stone. Just west of Summerville two small quarries have been in recent operation. The stone has been burned by the heap method. A mine nearby supplied the necessary coal. In one of the quarries the shale had slumped down, largely concealing the limestone stratum. In the other the following section was exposed in August, 1929.

Section of Vanport limestone in quarry west of Summerville

Shale	20 feet
Iron ore	2-4 inches
Limestone	16 inches
Shale and limestone	3 inches
Massive limestone (exposed)	3 feet, 9 inches

In Rose Township the Vanport is present near the hilltops in some places and elsewhere far down on the slopes of Redbank Creek and its tributaries, especially Fivemile and Smathers Run. It varies from 3 to 5 feet in thickness. In most places it is of good quality and has been locally quarried, but in a few localities it is shaly and siliceous and of little value.

In Knox Township the Vanport is found in a few places in the western part along the tributaries of Fivemile Creek but it appears to be absent in part or altogether along the south side of Sandy Lick Creek, although the strata which normally lie below and above are present. It also appears to be wanting in Winslow Township, either because

of non-deposition or removal before the deposition of the overlying strata.

Although the horizon of the Vanport is present in Union and Eldred townships, it does not seem to be developed there or, if at all, only in a few places.

North of Brookville in Pine Creek Township the Vanport has been recognized in a few places but it is a very sandy and worthless bed. It appears to pass gradually into a sandstone.

In Washington Township the Vanport appears to be generally absent. An exposure of 5 feet of ferruginous limestone one mile west of Rockdale may be the Vanport. It is highly fossiliferous and very dark in color.

In Warsaw Township the Vanport is present in the area between Mill Creek and the State Highway north of Reitz. It has been quarried in recent years on a small scale by Hiram Morris about 1 mile west of Sugar Hill Station and burned for lime. At present the operation is idle.

In the vicinity of Sugar Hill in Snyder Township the Vanport limestone is well developed near the tops of several small hills and has been quarried in numerous places. In 1929 two quarries were operated. One of these, located one-fourth mile northeast of Sugar Hill. has been operated part of every year since 1907, usually only in the winter, to supply lime for local agricultural use. Some stone is sold for structural purposes. In 1928 the owner, Mr. D. D. Long, sold about 10,000 bushels of lime. He has one limestone lime kiln. The ledge is about 5 feet thick, the upper portion composed of several rather thin layers, the lower portion massive. The stone is somewhat more dove-colored than usual and breaks with a glassy fracture, slightly resembling the Freeport limestones. Fossils are less numerous than in the typical Vanport of the Allegheny River region. The iron ore layer on top of the limestone is from 2 to 6 inches in thickness and contains many fossils of corals and brachiopods. The overburden in the quarry is about 8 feet.

About one-fourth mile east of Long's quarry, A. Bovaird has a similar operation but has worked on a smaller scale. Joseph Smith and Logan Bond have also quarried the Vanport in the same vicinity in recent years.

Ashburner reports (3, p. 240-241) an outcrop of the Vanport limestone in the bed of Toby Creek, Snyder Township, a short distance from the Elk County line, that is 10 feet thick. He saw 8 feet above water level and 2 feet below. This is the thickest bed of Vanport known to the writer to occur in Jefferson County. Ashburner describes it as follows: "The exposure consists of seams of limestone from 1 to 3 inches thick, which are heavily charged with iron. The structure of most of the limestone, where exposed, is concretionary, and the concretions contain the most iron. Small seams of iron pyrites and calcite are found running through portions of the limestone beds. The limestone seams alternate with blue and gray slate, from a few inches to 1 foot in thickness.

"The high percentage of iron which the Ferriferous limestone (Vanport) is found to contain, not only at this locality, but at others in the district, has led many to suppose that it was a workable bed of iron ore. While selected concretions will probably run high enough in iron to make it possible to use them as an iron ore, in the furnaces, no hope

should ever be entertained that the Ferriferous limestone will be found in this vicinity containing a percentage of iron sufficiently high to make it profitable to mine as an iron ore. This limestone bed is the same as is quarried in the hill east of Brockport."

Close to the road between Richardsville and Munderf the Vanport lies close to the tops of the hills in several detached areas and has been quarried in a number of places near the outcrop for stone to be burned for agricultural lime. The ledge was best exposed in 1929 in a small quarry about one-fourth mile northwest of the cross-roads at Munderf where it occurs in two massive layers, the upper 37 inches thick and the lower one 27 inches. In places the Vanport in this section is from 6 to 6½ feet thick. The shale overburden at this point is from 15 to 18 feet thick.

LIMESTONES ABOVE THE VANPORT

The limestones of Jefferson County above the Vanport are much less regular in every respect than the Vanport. Although seven different ones have been named, certain regions that should have all present may be entirely devoid of limestone. The Upper Freeport is the most persistent and the most valuable, with the Lower Freeport next. The limestone horizons of the Conemaugh group are confined to the southeastern part of the county.

The Johnstown limestone, formerly widely known as the Johnstown cement bed, is rather widely developed in Jefferson County. Where present it is 1½ to 2½ feet thick and is rather impure. It is dark bluish-gray to light brown, somewhat fossiliferous, hard and tough and breaks with an irregular fracture. In a very few places it has been quarried and burned for agricultural lime but the large percentage of impurities almost everywhere render it of very little value.

The Lower Freeport limestone lies a few feet below the Lower Freeport coal. It is poorly developed in Jefferson County, there being only a few places where it attains a thickness of more than 3 feet. It has been quarried in a few localities for lime and pulverized limestone. It is a dark gray or bluish-gray stone when fresh, but weathers to a light yellow color. It is mainly non-fossiliferous, compact, crystalline and breaks with a conchoidal fracture.

The Upper Freeport limestone is thickest in a narrow belt between Perryville and Worthville. It lies a few feet below the Upper Freeport coal. In the vicinity of Perryville it is about 10 feet thick including some interbedded shale. In a few places this member is 15 feet thick although within a few miles it may be no more than 3 or 4 feet, the ordinary thickness. Certain layers are fairly pure and yield a good grade of lime, whereas others are quite impure. In physical and chemical composition it varies widely.

The Mahoning, Brush Creek, Woods Run, and Ames limestones are mainly impure and only locally developed in the southeastern corner of the county. With the exception of one occurrence of the Ames with a thickness of 14 feet, these limestones are thin.

In Porter Township, the Upper Freeport limestone is developed near Porter. At one place Platt (2, p. 5) describes it as "6 feet thick consisting of good stone, compact, brittle, and exhibiting its usual minute univalve shells. It has long been quarried both on the Travis and McClelland farms, having been opened many years ago, when old Phoenix

furnace near Milton was in blast. The exposure at McClelland's is the only good one of the Freeport upper limestone in Porter township."

In Perry Township the Johnstown limestone is represented in the vicinity of Perryville where it is 3 feet thick (2, p. 10). "The rock is hard and tough, with irregular fracture; its color is dark bluish gray; it is fossiliferous; its composition is rather that of an impure limestone than of a cement. (For analysis, see table on page 442, analysis 10).

Near Foundry Run the Upper Freeport limestone is well exposed. Platt (2, pp. 10-11) describes it as follows: "It is 10 feet thick, divided into three layers by small partings of shale. The top layer is an impure cement; the centre bench consists of excellent limestone; the bottom bench though less pure than that above makes good quarry lime. Minute fossil shells were observed in all three benches. (For analysis, see table on page 442, analyses 4a, 4b).

Farther north on Foundry Run the Upper Freeport limestone measured 8 feet in one place and 5 feet in another. South of Valier and on the opposite side of Mahoning Creek north of Fordham, the Upper Freeport limestone has been quarried in small operations for agricultural lime. On the hilltops near Grange and extending to the northwest corner of the township, limestone is developed in several detached areas. It is about 6 feet thick and has been extensively quarried in the past for agricultural lime. (For analysis, see table on page 442, analysis 5).

In Young Township the Upper Freeport limestone has been reported at Lindsey (formerly Claysville) in the bed of the creek where it is ferruginous and otherwise impure. Ashley (5, pp. 56-61) shows a thickness of 6 feet here and 2½ feet just north of Punxsutawney. He also reports the Woods Run limestone with a thickness of 29 inches, the Pine Creek limestone with a thickness of 30 inches, and Mahoning limestone with a thickness of 12 inches, all to the southwest of Punxsutawney.

Ashley (5.) reports the occurrence of the Ames limestone in Bell Township in the divide between Rook and Trout runs with a thickness of 14 feet and the Mahoning limestone with a thickness of 4 feet near Canoe Creek (Cloe P. O.). In Gaskill Township he shows sections of the Upper Freeport limestone as follows: 14 feet thick just north of Big Run, 2 feet thick near Winslow Station, and 12 inches thick near the head waters of Clover Run.

In Ringgold Township the Upper Freeport limestone has been reported in several isolated localities in the basin of Little Sandy Creek and is known to have been quarried for agricultural lime in a few places.

In Oliver Township the Upper Freeport limestone is reported to occur near the hilltop about 2 miles northwest of Cool Spring. (For analysis, see table on page 442, analysis 6).

In Henderson Township, Platt (2, pp. 73-74) describes two limestone ledges about 73 feet apart on the divide between Windfall and Big runs and another one 70 to 80 feet higher about 1½ miles farther east on a road leading to Stump Creek. The thicknesses were estimated to be about 3 feet each. Samples from each of the three strata analyzed by McCreath are given in table on page 442, analyses 1a, 1b, 2.

Ashley (5) gives sections of the Ames limestone, 2, 4-2/3 and 5-feet in thickness respectively in this same general locality. They probably represent at least one of the beds described by Platt.

Northward near the headwaters of McKee Run, Platt (2, p. 74) describes a limestone more than 6 feet thick. Near the middle of the boundary line between Henderson and Winslow township he states that limestone was one time quarried.

Near the East Branch in the eastern part of the township Ashley gives a section of 26 inches of the Mahoning limestone.

The Upper Freeport limestone is developed on the hilltops north of Worthville in Beaver Township. It is composed of layers of different color and composition, aggregating about 15 feet in thickness. Some are of good quality, others not. The Lower Freeport and Johnstown limestones have also been recognized in the same vicinity.

The Upper Freeport limestone is not well developed in Clover Township as it has largely been removed by erosion. However, it is present in some of the higher hills northwest of Summerville near the Clarion County line where it is over 4 feet thick.

In Knox Township the Freeport limestones are practically absent although one exposure of limestone has been reported close to the McCalmont Township line.

A limestone stratum several feet thick has been reported from near the mouth of Sugarcamp Run in the southeastern part of Winslow Township. The most active limestone operations in the township have been at Pancoast where for more than 50 years the Lower Freeport limestone has been intermittently worked for lime burning. In 1928 the Reynoldsville Lime Company working here sold 559 tons of hydrate and 467 tons of pulverized limestone. There are several different kinds of rock in the quarry, ranging from a high grade, well crystallized stone to the dove-colored, fine grained, non-fossiliferous variety that breaks with a pronounced conchoidal fracture. Conditions are not favorable for a large output. At Sandy Valley the writer was told of the existence of a limestone ledge but it was not exposed at the time of our visit in 1929.

In Union Township the Lower Freeport limestone lies near the top of a hill about 1 mile southeast of Corsica. (For analysis, see table on page 442, analysis 8).

Both the Lower and Upper Freeport limestones are reported to be present between Rockdale and Allens Mills and in the vicinity of Rattlesnake Run, Washington Township. Platt (2, p. 170) gives a quarry section of the Lower Freeport limestone near Allens Mills as follows:

	Ft.	*in.*
Limestone, good	1	3
Clay shales		5
Limestone		6
Limestone, impure		8
Limestone, good	1	3

The Lower Freeport limestone has been reported to be present in a few places in Eldred Township.

In Snyder Township the Upper and Lower Freeport and the Johnstown limestones have been reported. South of the Little Toby Creek at Brockwayville the respective thicknesses are 5, 2½ and 2 feet. Analyses of samples from these beds are given in the summary table, analyses 3, 7, 9.

Analyses of limestones of Jefferson County

	1a	1b	2	3	4a	4b	5	6	7
$CaCO_3$	92.500	75.357	77.143	89.107	48.571	90.000	91.875	88.928	87.035
$MgCO_3$	2.497	9.330	4.691	1.611	23.762	2.860	2.421	1.589	1.558
Al_2O_3, Fe_2O_3	1.530	4.230	3.790	2.140	7.250	1.285	1.312	1.740	2.170
SiO_2	2.390	9.780	11.780	6.170	16.660	3.480	3.130	6.770	8.400
P.	.023	.017	.073	.024	.032	.011	.012	.023	.057

	8	9	10	11	12	13	14	15
$CaCO_3$	92.857	51.410	82.393	94.392	93.643	96.428	96.578	39.428
$MgCO_3$	1.680	3.962	1.891	1.702	1.816	.908	.832	1.816
Al_2O_3, Fe_2O_3	2.320	7.790	4.653	1.315	1.310	.990	.780	4.760
SiO_2	2.070	----	----	1.910	2.040	1.300	1.280	51.450
P.	.019	.033	.300	.031	.030	.034	.037	.011
Insoluble residue	----	33.900	8.020	----	----	----	----	----

Descriptions of foregoing specimens:

1. (a) Property of James Smith, 2 miles northeast from Big Run. In Lower Barren measures, 200 feet to 225 feet above Freeport Upper coal. Rather coarse grained, brittle, bluish gray. (4, pp. 87-88) (b) Same as above, but 125 feet to 150 feet above Upper Freeport coal. Fine grained; rather hard and tough; pearl gray. (4, pp. 87-88)

2. Jacob Smith, 2 miles north from Big Run. 150 feet to 175 feet above Freeport Upper coal. Fine grained rather brittle; with conchoidal fracture; irregularly seamed with calcite; dark bluish gray. (4, pp. 87-88)

3. Upper Freeport limestone. N. B. Lane's property, 1 mile southeast from Brockwayville. Fine grained; brittle; sparkles with calcite; generally pearl gray. (4, p. 88)

4. Upper Freeport limestone. John Iler's property. 1 mile N. W. from Perryville. (a) Upper bench. Hard and tough; appearance sandy; fracture, irregular; color, light pearl gray; (b) Lower bench (?) Rather fine grained; comparatively brittle; mottled with calcite; bluish gray. (4, p. 88)

5. Freeport limestone. From property of D. Hopkins, 2 miles northwest from Frostburg. Very fine-grained and brittle; mottled with calcite; pearl gray. (4, pp. 88-89)

6. Freeport limestone. From property of A. Huffman, 2 miles northeast from Northville. Fine-grained; brittle; mottled with calcite; pearl gray. (4, pp. 88-89)

7. Lower Freeport limestone. N. B. Lane's property, one mile southeast from Brockwayville. Fine-grained; hard and brittle, brownish gray. (4, pp. 88-89)

8. Lower Freeport limestone. From Evans Round Top, one-half mile east from Corsica. Fine-grained; hard and brittle; brownish gray. (4, pp. 88-89)

9. Johnstown cement bed. N. B. Lane's property, one mile southeast from Brockwayville. Hard and tough; argillaceous; more or less stained with iron oxide; color, generally dark gray. The ignited "insoluble residue" contains: silica, 27.570; alumina, 4.800; sesquioxide of iron, trace; lime, trace; magnesia, .245 (J.M.S.) (4, p. 89)

10. Johnstown cement bed. John Iler's property, one mile northwest from Perryville. Rather hard and tough; fracture, irregular, rough; dark bluish gray. (4, p. 89)

11. Vanport limestone. C. Bovaird, 3 miles northwest of Brockwayville. Fine-grained; brittle; pearl gray. (4, pp. 89-90)

12. Vanport limestone. From property of William Hanna, 2 miles northeast from Sprankle's Mills. Hard and tough; fine-grained, full of fossil casts; dark bluish gray. (4, pp. 89-90)

13. Vanport limestone. From property of A. Enty, one-half mile southeast from Worthville. Fine-grained; brittle; fossiliferous; light bluish gray. (4, pp. 89-90)

14. Vanport limestone. Samuel Shield's property, one mile north from Dowlingville. Rather fine-grained; fossiliferous; sparkles with calcite; pearl gray. (4, p. 90)

15. Near Frost's house, four miles east from Brookville, on Ridgeway road. Appearance, sandy, exceedingly hard and tough; fracture, slightly conchoidal; color bluish gray. (4, p. 90).

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There are only a few geological publications describing the limestones of Jefferson County. These have been freely drawn upon to supplement the writer's observations.

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1. Report of progress in the Clearfield and Jefferson District of the Bituminous Coal-Fields of Western Pennsylvania, by Franklin Platt. Report H, 296 pp., Harrisburg, 1875.

2. Report of progress in Jefferson County, by W. G. Platt, Report H6, 218 pp., colored geological map of the county, Harrisburg, 1881.

3. The Township Geology of Elk and Forest Counties, by Charles A. Ashburner, and of Cameron County, by Arthur W. Sheafer. Report RR, Part II, 405 pp., Harrisburg, 1885. Brief references to Jefferson County, especially pp. 240-241.

4. Third Report of progress in the Laboratory of the Survey at Harrisburg by Andrew S. McCreath. Report M3, 126 pp., Harrisburg, 1881. Contains analyses of Jefferson County limestones, pp. 87-90.

Pennsylvania Geological Survey, Fourth Series

5. Topographic and Geologic Atlas of Pennsylvania, No. 65, Punxsutawney Quadrangle. Geology and Mineral Resources by George H. Ashley. 145 pp. Geology map. Harrisburg, 1926. Contains brief descriptions of limestones in the southeastern part of Jefferson County.

JUNIATA COUNTY

Limestones are widespread throughout Juniata County. Of the 13 townships in the county, only Greenwood appears to have no limestone of economic value. Nearly all of the limestones belong to the Helderberg (including Tonoloway) group, but limestones belonging to the Ordovician System, and the Salina and Onondaga are also developed sparingly.

At present there is little activity in limestone quarrying. Although scores of abandoned quarries can be seen throughout the county, nearly all are small. They were mainly worked by farmers who quarried and burned a little stone occasionally for use on their own farms and to sell to their immediate neighbors. Some was used on the roads and for the construction of houses. Nowhere in the county do the limestones appear to be sufficiently thick and pure to justify any large development. The few quarries that have been worked in recent years have furnished stone for highway construction, concrete structures, and for burning for agricultural use.

CANADIAN AND ORDOVICIAN LIMESTONES

The only limestones of the Canadian-Ordovician in Juniata County are exposed in Black Log Valley in the extreme northwest corner of the county. The talus from the shales and sandstones of the adjoining hills largely conceals the limestone but it is reported to have been quarried on a small scale at one time. Its limited distribution prevents it from being of any economic importance. It seems to represent the top of the series so prominently developed and extensively worked in Kishacoquillas Valley in Mifflin County.

HELDERBERG LIMESTONES

The Helderberg (including Tonoloway) limestones of Juniata County extend in two continuous bands across the entire county from northeast to southwest.

The northern band enters the county at Richfield and runs westward through Cocolamus and McAllisterville, bending south at the latter village and outcropping about a mile north of East Salem. It then runs southwest for about ten miles to a point southeast of Mifflintown where it is sharply folded and extends across Juniata River nearly to Allendale. From Mifflintown the outcrop on the south flank of the fold bends back to the southeast, passing directly south of East Salem. The line of outcrop then reverses its direction and crosses Juniata River at Port Royal where excellent exposures of it can be seen along Tuscarora Creek. It continues the southwestward trend past McCoysville and Peru Mills, leaving the county along the southwestern line.

The southern band enters the county east of Thompsontown and extends in a westerly direction, crossing Juniata River near Mexico and passing through Pleasant View and Honey Grove, and leaves the county near Waterloo.

In practically every place where the Helderberg has been quarried

in the county considerable shaly stone of little value is encountered. In most openings the dark blue limestone that was quarried is from 20 to 30 feet in thickness although in a few places it is as much as 60 feet thick. In seeking suitable stone attention must be given to avoid the more shaly beds. If this is done, a fairly large quantity of good stone can be obtained.

DESCRIPTION BY DISTRICTS

Cross Keys—Peru Mills—McCoysville Area. East of Cross Keys, on the Vaughn property, the Helderberg is cut by a small stream and a considerable thickness of strata is exposed. The beds are very hard and siliceous. A small amount of material has been removed for lime burning purposes. The overburden, consisting of flint and shaly limestone, is very deep and would interfere with development. The rock in the southern end of the exposure is rather thin bedded.

Half a mile east of McCoysville the abandoned Whittock quarry is located. The height of the working face is about 45 feet and the width about 60 feet. The strata dip about 45°S. The first bed on the south is a massive, gray, crystalline limestone 10 feet thick and analyzing 96 per cent $CaCO_3$. It produces a peculiar odor when struck. The remaining beds to the north are of a blue gnarly character, averaging about two feet in thickness, becoming very thin bedded and of a light blue color at the north wall. The limestone forming the wall is shaly and of low specific gravity, reminding one of thick cardboard. Sun cracks are well developed on this material.

The gnarly blue beds in the quarry contain many fossil brachiopods, mollusks and crinoids. The gray crystalline beds exhibit beautiful specimens of coral and tiny brachiopods. The south wall is composed of a tough brown bed of rotten shale containing nodules of limestone. This bed caused great difficulty in the quarry operation as did the thin bedded material to the north side of the quarry.

The overburden proper is not deep, averaging about three feet. However, the clay penetrated to a depth of about 20 feet between the beds and had to be blasted down with the stone.

A well 120 feet deep failed to penetrate the limestone at this point and provided only two gallons of water per minute.

Tuscarora Valley Area. The Helderberg extends across the county in the valley lying to the north of Tuscarora Mountain and has been worked in a great many places.

North of Honey Grove, the abandoned Allen quarry is located on the south flank of the most northerly of the two limestone ridges. The quarry has been but little developed. Bedding could not be seen, but farther to the east, the thin-bedded blue limestone dips into the base of the hill. The strike of the formation at this point is N.45°. The bottom layers in the quarry are very hard and somewhat siliceous. Fossils are entirely lacking. The middle beds are more or less crystalline and deep blue in color. Few fossils occur in the middle portion, but above this more or less crystalline layer the beds are very fossiliferous. All the fossils are poorly preserved. Among them are corals, crinoids, and a few brachiopods. The old Allen quarry is probably the only good exposure in the western end of the valley.

In the eastern end of the same valley, the abandoned quarries in Turbitt and the adjoining townships show the Helderberg very well. The first quarry in this area is located high along the hillside about 1½ miles from Port Royal on the road to Ickesburg. In this quarry the beds appear to be quite massive and can be followed along the hillside for some distance. The pike cuts across the strike of the formations and shows them to be quite shaly. Along the road from Tuscarora Creek to the main highway from Port Royal to Ickesburg 32 different layers were counted in a thickness of three feet.

The second quarry is located along the same hillside about half a mile east of the road forks and here the rocks have apparently the same attitude as in the first quarry—strike N.69°E. and dip 42°NW. The lower layers appear to be more or less rotten and gnarly and very thinly bedded, but a deep cut along the hillside farther down the dip revealed massive beds of a blue gray to a gray fossiliferous crystalline limestone. Considerable clayey matter is present. A kiln at the base of the hill is being operated by Mr. Groneger.

About 400 yards farther east and along the south side of the road, about 10 feet of strata are exposed. They show practically the same lithological features and attitude as noted above.

Along the south side of the road near Hertzler's store, there is an excellent outcrop of the *Tentaculites* bed and the exact position of the Helderberg can be seen. Several rods to the east is a quarry in the Shriver chert member, and still farther east, the Oriskany is exposed in the railroad cut of the Tuscarora Valley railroad.

Just north of Mexico Station on the Pennsylvania R. R., on the west side of Juniata River, there is an excellent exposure of Helderberg limestone. The strike of the beds is approximately parallel to the railroad so that only about 150 feet of beds is exposed although the cut is about one-fourth mile long. Most of the limestone is gnarly and tough, with many fossils in certain layers, but near the base the beds are decidedly shaly. Some of the massive beds might furnish satisfactory stone for construction purposes, but the stone from this place was condemned by the State Highway testing laboratory.

This formation can be traced across Juniata River about one mile below Mexico Station where it was studied in Benner's quarry. In this quarry the main mass of rock has been extracted along the strike. Here the cut is 50 feet wide and runs practically due east-west. The rock for the most part is used for township road work, although the immediate community is also supplied with burned lime.

The Hamilton quarry is one and one-half miles farther east and shows a thin, platy formation with beds averaging six inches to three feet in thickness. But as in the Benner quarry, the better grade of stone has been removed.

A short distance southwest of the station at Mexico there is a ridge about 125 feet in height with a trend of about N.75°E. On the north side of this ridge there is a band of Helderberg limestone about 100 feet in width which is low in silica but both overlain and underlain by thin-bedded, shaly, fossiliferous, high-silica limestone. The strike of the strata is N65°E with dips to the northwest from 45° to 75°. An average of 17 samples of the low silica stone is as follows:

Analysis of Helderberg limestone near Mexico

$CaCO_3$	93.28
$MgCO_3$	2.03
SiO_2	2.11
$Al_2O_3+Fe_2O_3$	1.12
S	.03

The Hamilton quarry is 1½ miles farther east and shows a thin, platy formation with beds averaging six inches to three feet in thickness. But as in the Benner quarry, the better grade of stone has been removed.

Johnstown-Mifflintown-McAllisterville-Richfield Area. The Helderberg limestones form a continuous band from Mifflintown to Richfield in a fairly straight line, except near McAllisterville, where several local folds cause the limestone to be offset to a distance of about 1½ miles. They are found in the valleys of Lost, Cocolamus, and west branch of Mahantonga creeks. In this distance there are a great many abandoned quarries where stone was once quarried for lime burning. Most of them expose from 15 to 40 feet of dark colored to gray limestones, some of which break with a glassy fracture and others are harder and more siliceous. Shaly beds are common and yet, with care, stone acceptable for lime burning or for highway purposes can be obtained. During the summer of 1931, only a few quarries were in operation in this area.

East of Johnstown on the Mason Pardner farm, a bed of limestone 12 feet thick caps the top of a long low hill. The beds dip about 10°N. The stone is bluish white and breaks with a blocky fracture, producing many slabs. Brown shale at least 30 feet thick underlies the limestone. Exposures at Mifflintown show the same strata.

The most active quarry seen in Juniata County in 1931 was located about 1½ miles southeast of McAllisterville and worked jointly by the Mapleton Limestone Company to obtain stone for the State highways and by Amos Lauver to get stone for burning in 2 kilns which he had in operation. The height of the working face ranges from 50 to 60 feet. Over most of the quarry the beds are practically flat but at the south side bend down steeply. The stone is mainly in rather massive beds of bluish-black to gray limestone with only a small amount of shaly material. There is an overburden of 8 to 10 feet of rotten rock which must be stripped and wasted. Beneath this layer some of the stone is altered to a yellowish earthy color, but this is only superficial and the stone is still solid. Only one prominent clay pocket was seen. For the crusher, the stone is loaded in part by steam shovel but in part by hand. The stone burned for lime is all carefully picked and loaded by hand.

About 1 mile south of Evendale, Page and Fosselman are operating on a small scale to get limestone to supply a small kiln. They are working in a quarry that about 1925 was worked for road stone. Beneath a layer of soil and rotten rock about 1 to 2 feet thick, there is a bed of gnarly thin-bedded rock which in turn overlies massive limestone of good quality for either lime or crushed stone.

On the road to Cocolamus, a short distance east of McAllisterville, the Lennart quarry, now abandoned, shows two layers of a rather hard, blue limestone, about 25 feet thick. Included in the formation near the base is a 6-inch ledge of shaly material. The rocks dip about 15°SE.

North of Cocolamus there are three abandoned quarries, Emey, Hoffman, and Erisman-Smith. There are four old kilns on the properties and the people say that quarries in this section date back to 1797. The upper layers in the Erisman-Smith quarry show a flinty overburden and are made up of grayish, impure limestone which contains few fossils. Directly beneath this grayish limestone there is a blacker limestone which reaches a thickness of about 12 feet. This latter rock breaks with a distinct glassy fracture. Beneath it the limestone becomes somewhat siliceous.

Following Lost Creek westward along the northern flank of Lost Creek Ridge, one comes to the Foulkrod quarry. Here the anticlinal arch of the valley can be seen, the southern flank being well exposed at the east end of the quarry, which is about 65 feet high and about 100 yards long. The rocks dip 40°SE and quarrying is simplified by the shattering the rocks have suffered. Four kilns on the property were producing 16 tons of lime a week in 1921. The selling price of lime was then $7 a ton.

Section exposed in the Foulkrod quarry

	Feet
Keyser limestone:	
Shaly limestone, not good for lime	8
Blue to black limestone, shattered	20
Blue gray limestone, very hard	1½
Bluish-black limestone ("quarry rock"), veins	35

In that portion of the Lost Creek Valley where the limestone belt broadens out, a quarry has been opened and then abandoned. The operator was a Mr. Stouffer. The beds exposed are practically the same as at the Foulkrod operation.

SALINA, MARCELLUS AND ONONDAGA LIMESTONES

Impure limestones of little economic importance, although they have been worked on a small scale in a few places, have been noted within the Salina, Onondaga and Marcellus formations of the county. It seems probable that the limestones referred to the Marcellus should be referred to the Onondaga. The Salina limestones are best developed in Walker and Milford townships and the Onondaga in Fayette Township, where an 8-foot bed of fair stone of a dark blue color was once quarried at Browns Mill (Cocolamus P. O.), in Delaware Township where it is about 15 feet thick and impure, in Milford Township, in Tuscarora Township where there is a 10 to 15 foot bed of greenish limestone which weathers to a buff color, and near Peru Mills in Lock Township where a rather shaly limestone is developed.

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LACKAWANNA COUNTY

There are no limestones of economic importance in Lackawanna County. Within the Catskill group, consisting almost entirely of sandstones, there are some beds of calcareous sandstones or breccia that have been called limestones locally. One of these exposed in the vicinity of Crystal Lake, has been termed the Cherry Ridge limestone, but it really is sandstone with a low percentage of lime.

LANCASTER COUNTY

Lancaster County has a greater area of exposed limestone than any other county of Pennsylvania, and all the limestones belong to the Cambro-Ordovician series except some undeveloped Triassic conglomerates in the vicinity of Bainbridge. They form a practically continuous broad, east-west band that traverses the central part of the county, and constitute the surface rocks of one-half the county. The fertility of the residual soils formed by the decay of these limestones is especially high and has won for Lancaster County the enviable position of the richest agricultural county of the United States.

As in other sections of the State, the relatively soluble limestones underlie the valleys. The higher ridges in the northern and southern portions of the county are composed of sandstones, shales, schists, gneisses, trap, and other varieties of resistant rock.

Uses. The limestones of Lancaster County have been quarried in almost every section of the limestone belt. In the Lancaster quadrangle Professor H. Justin Roddy has found 191 localities where limestone quarries have been opened. As this comprises less than one-third of the limestone area of the county, it is probable that there are as many as 300 abandoned and working limestone quarries altogether. As in other sections of the State, most of these quarries were small openings that furnished only a limited amount of stone for local use and have long since been abandoned.

Probably the earliest use of Lancaster County limestones was for building purposes and there are many fine old residences throughout the county that show the beauty of the local limestones. On the whole the limestones of the region are not well adapted for such use as there are few places where good building material can be obtained without an undue amount of waste. Most of the stone is closely jointed and the joints intersect at such angles as to require much work in dressing. The marble of the county is said to resist weathering poorly. However, some buildings are constructed entirely of local limestone and it has generally been used throughout the limestone belt for foundations.

For many years the farmers used lime freely for fertilizing the soil and many small quarries were opened to furnish the stone for the small local kilns. At present few farmers can afford to make the lime that they need because agricultural lime can be bought so cheaply, and the small farm kilns are now in ruins. In a few places, favorably situated for shipping, lime is still being burned and in large quantities. The largest operations in recent years have been the J. E.

Baker quarries at Billmeyer along Susquehanna River and the Bellemont quarries southeast of Kinzers.

Limestone and dolomite have been quarried for flux in several places. When the local iron ore mines were in operation, a number of furnaces were supplied with limestone from nearby quarries. Several quarries in the Marticville region were worked for flux to use in the nearby iron furnaces. Lancaster County limestone was also used to smelt the nickel ores that were long mined near Gap. With the closing of the iron mines and furnaces of the region, the use of the local limestone for flux has diminished. The requirements for fluxing stone that can be shipped to compete with other limestones have increased so that now only the best quality stone can be regarded. The J. E. Baker Co. has shipped considerable low magnesian and high magnesian fluxing stone from their extensive quarries at Billmeyer and formerly quarried a dolomite near Bamford that was shipped for flux. The analyses that follow show that good fluxing stone occurs in several places in the county.

Since the development of macadam and concrete roads and concrete structures of all kinds, there has been an excessive demand for crushed limestone and many abandoned quarries have been reopened and new ones have been developed. The Cambro-Ordovician limestones almost everywhere in the State possess the requisite qualifications for road building and concrete and Lancaster County has supplied much crushed stone for use both within and without the county. Some of the localities where large quarries are worked for crushed stone are the following: one mile southeast of Columbia, 3 miles northwest of Lancaster, the Orchard quarry at Quarryville, and the Bellemont quarries southwest of Kinzers. There are scores of places where desirable stone for crushing can be obtained if at any time the demand cannot be met by the present operations.

Two different areas have been prospected with the idea of building Portland cement plants. One of these is located one mile west of Brownstown and the other one mile northwest of Florin. It is believed that careful investigation might result in the location of satisfactory deposits for this purpose but it is evident that detailed examination is necessary.

For a short time some stone was quarried about 3 miles south of Mount Joy for the purpose of extracting the magnesia. It is a low-silica dolomite.

Division of the limestones into formations. Until recently the limestones of the Lancaster Valley had not been differentiated although the paleontological work of Professor Roddy of Franklin and Marshall College had proved the existence of both Cambrian and Ordovician strata. Stose and Jonas (10, pp. 358-366) have proposed the classification of the limestones given in the following table.

Generalized geologic section of Lancaster County

Age	Name	Thickness (feet)	Character of rocks
ORDOVICIAN	Conestoga limestone (probably older than, or in part equivalent to, Cocalico shale).	1000±	Dark slaty limestone, coarse limestone and marble conglomerate, thin-bedded granular blue limestone, micaceous limestone and thin graphitic slate. Contains brachiopods and crinoid plates and stems of probably Chazy age. Overlaps southeastward on all formations from the Ledger dolomite to the Harpers schist.
	Cocalico shale series	2000±	Dark gray shale containing graptolites of Normanskill type and thin crinoidal limestone at base; gray, green, and purple slates and green impure sandstone above.
CANADIAN	Beekmantown limestone series	2000±	Light blue and gray pure limestone, light gray magnesian limestone and dolomite, containing a little chert. Carries Beekmantown fossils.
	Conococheague group	1000±	Massive light blue limestone containing Cryptozoon reefs, thin-bedded wavy laminated limestones, fine grained white marble, sandstones and sandy conglomerates, and dolomite.
CAMBRIAN	Elbrook group	1000±	Cream-colored to white, fine-grained impure marble, mostly thinly laminated to shaly. Weathers to shaly yellow tripoli and yellow earthy soil.
	Unconformity		
	Ledger dolomite	1000±	Granular, gray to white dolomite, mostly thick-bedded, some beds of which are siliceous and weather to rust-stained granular cherty layers. Forms deep red granular soil.
	Kinzers formation	200	Siliceous banded dark blue limestone, impure dolomite weathering to dense buff tripoli, spotted white marble with wavy impure partings, and in lower part shale which contains an *Olenellus* fauna.
	Vintage dolomite	500-650	Massive, glistening, coarse-grained, dark gray dolomite, weathering whitish with scattered crystalline blebs, and dark blue dolomite with argillaceous partings, weathering knotty or lenticular.

The Vintage, Kinzers, and Ledger are equivalent to the Tomstown dolomite.

The following descriptions are taken largely from the published works of G. W. Stose, A. I. Jonas, and E. B. Knopf (see bibliography at close of chapter).

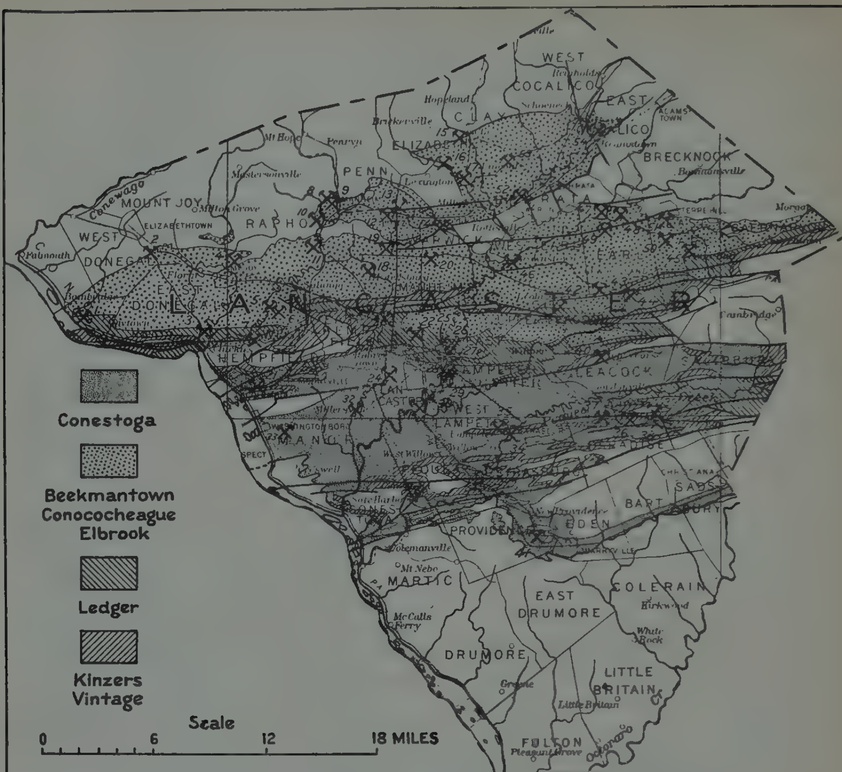


Fig. 17. Limestone areas in Lancaster County.

1. J. E. Baker Co. 2. Penn Lime and Stone Co. 3. Jacob Strickler. 4. J. N. Stauffer & Bro. 5. N. S. Newcomer & Son. 6. A. M. Eshleman. 7. I. S. Siegrist. 8. C. C. Winters. 9. Harry E. Gantz. 10. A. F. Metzgar. 11. J. L. Kauffman. 12. J. D. Bucher. 13. Theodore L. Forney. 14. Binkley Bros. and Ober. 15. Isaac Stauffer. 16. C. P. Risser. 17. John Seibert. 18. Binkley and Ober. 19. Thomas H. Erb. 20. Abraham E. Binkley. 21. Clarence D. Stoner. 22. J. C. Buddine. 23. Dolomite Products Co. 24. Clarence D. Stoner. 25. Clarence D. Stoner. 26. Conestoga Traction Co. 27. John B. Heidig. 28. Walter B. Kendig. 29. J. M. Brenner. 30. Denlinger and Johnson. 31. Brenner and Heistand. 32. H. R. Miller. 33. Brenner and Heistand. 34. Aldus Zittle and Bro. 35. Lampeter Township quarry. 36. Bellemont quarries. 37. J. L. Denlinger. 38. E. A. Slaymaker. 39. Jacob Z. Landis. 40. A. B. King. 41. Orchard quarry. 42. Levi F. Zook. 43. Elmer Meyers. 44. Aaron Good and Bros. 45. J. C. Showalter. 46. Eli W. Shreiner. 47. Henry Martin. 48. David Burkholder. 49. William R. Good. 50. Ferris Martin. 51. C. S. Martin. 52. A. C. Kurtz and Sons. 53. S. B. Keller. 54. R. M. Hertzog.

CAMBRO-ORDOVICIAN LIMESTONES

Vintage dolomite. "The Vintage dolomite (4, pp. 24-25) comprises in general a heavy-bedded gray dolomite, which weathers to a whitish chalky surface, and a knotty dark-blue dolomite with hard argillaceous beds and partings. Some of the beds are sparkling gray to blue, mottled with lighter or darker siliceous and calcareous blebs that stand out in relief on the weathered surfaces. The impure basal beds are a cream-colored to pinkish-white fine grained marble, in places micaceous, which contains sphalerite at one place in the

Manor Hills and is a distinctive horizon marker generally recognizable by its lithologic character. The dolomite weathers to a characteritsic dark-red or maroon granular soil with few rock exposures. The best exposure of the formation in the region is in the cut of the Pennsylvania Railroad at Vintage, 13 miles southeast of Lancaster, where the following section was measured:

Section in cut of the Pennsylvania Railroad west of Vintage, Pa.

	Feet
Kinzers formation:	
Dark graphitic shale.	
Argillaceous dolomite with dark carbonaceous partings; weathering to earthy rock or tripoli in which fossils are evident	7
Vintage dolomite:	
Light-gray massive dolomite without bedding	33
Covered; probably dolomite	100±
Massive sparkling gray-blue mottled dolomite; weathers chalky with siliceous and calcareous blebs in relief	30
Blue dolomite, wavy bedding, with micaceous partings	25
Thin micaceous shale	5
Blue argillaceous dolomite; weathers to thin slivers, with some blue massive dolomite bands	15
Granular dolomite, light gray mottled with blue, in 5-foot beds	35
Dense darker blue massive dolomite with some granular blebs and argillaceous partings; weathers chalky	100
Light and dark mottled dolomite	35
Gray massive dolomite with wavy partings and granular blebs	150±
Largely covered; probably dolomite; dark glistening dolomite, in part thin-bedded, near base	200±
	728±

"The Vintage dolomite makes a narrow band, more or less disjointed by faulting, along the south foot of Chestnut Hill from Columbia to its east end, northwest of Rohrerstown. The band swings northward around the plunging end of the Chestnut Hill anticline and makes a belt of somewhat greater width around the northern part of Chestnut Hill to Marietta Junction. It underlies most of the lowland between Silver Spring and Chestnut Hill. Several small areas of the Vintage dolomite occur in the triangular fault blocks northwest of Marietta Junction. The dolomite forms most of the lowland which extends from a point near Landisville to Landis Valley. Another area of the formation surrounds the hill of Antietam sandstone near Binkley. A belt of Vintage dolomite surrounds the anticlinal hill of Antietam quartzite south of Mountville, and very narrow bands of the formation with few outcrops surround the other anticlinal hills of the Antietam and older formations in the Manor Hills."

"The Vintage dolomite (6, pp. 50-51) is exposed north and west of Mine Ridge upland on the slopes of the 'sand hills,' made up of Antietam albite schist, which it surrounds. It occupies valleys also between the Cambrian schists and the blue slaty Conestoga limestone. North of Gap it underlies the valley west to Bellemont and Leaman Place and forms a narrow valley that extends 8 miles west of Bellemont. The best exposures lie in the cuts of the Pennsylvania Railroad from Leaman Place to Kinzers. There is a large quarry in Vintage dolomite now operating at Kinzers, north of the Lincoln Highway, where the rock quarried is crushed for road metal. In

the valley of Pequea Creek north and east of Lime Valley there are many good outcrops of dolomite in stream cuts and old quarries. It is well exposed farther southwest along Pequea Creek near Burnt Mills."

"The Vintage dolomite (3, p. 11) occurs in six areas in the New Holland quadrangle. In places it occupies valleys between ridges of Antietam quartzite and of the overlying Kinzers formation ...... It occurs near Vintage in the southeastern part of the quadrangle, and in narrow areas south of Ledger and Salisbury, on the flanks of Hollow School and Laurel Hill ridges and south of Geist."

Kinzers formation. "The Vintage dolomite (4, pp. 26-28) grades up into the Kinzers formation, which makes narrow ridges separating the valleys underlain by the Vintage from the valley areas of Ledger dolomite. The most conspicuous ridges of the formation are those which extend through Bamford and Mountville. The formation consists of hackly blue shale with thin earthy dolomite which weathers ribbed and white spotted nodular marble (called in the field 'leopard rock') with blue to buff wavy dolomite partings that weather to a peculiar knotted wavy structure.

"At the base there are thin beds of impure dolomite which grades into the underlying Vintage dolomite and weathers to a fossiliferous yellow earthy rock or tripoli. A section measured in the cut of the Pennsylvania Railroad at Kinzers, 13 miles southeast of Lancaster, is as follows:

Section of Kinzers formation at Kinzers, Pa.

	Feet
Dark-blue limestone with wavy partings	10
Thick light-gray dolomite	12
Dark-blue limestone with wavy partings	6
Spotted white nodular marble with buff dolomite partings ("leopard rock")	5-10
Blue limestone with some siliceous banding, slightly wavy	8-10
Highly siliceous banded dark limestone, weathering to buff earthy network	8-6
Thick-bedded earthy dolomite, weathering to tripoli	2-4
Spotted white marble with some crenulated dolomite partings ("leopard rock")	8-6
Wavy banded blue limestone with fine argillaceous laminations at top	10
Dark fissile shale	35-70
Fossiliferous earthy blue dolomite, weathering to buff or orange-colored tripoli with hard brown skin; irregular base with dolomite pebbles	7
Massive light-gray dolomite (Vintage)	
	150±

"The Kinzers formation (4, pp. 28-29) makes a line of low knobs and ridges near the foot of the south slope of Chestnut Hill. Northeast of Columbia, where the dips are gentle, the white spotted marble and ribbed impure limestone above the shale are well exposed. Farther east only a thin band of shale has been seen, probably because of steep dips and narrow outcrops. At Mountville the shale makes a rather prominent hill where it lies in a syncline between the Chestnut Hill and Mountville anticlines. A slender band of shale and white spotted marble lies along the north side of the North Manor Hill anticline, following Strickler Run. Northeast of the Marietta road the dips are

again gentle and the upper part of the formation makes a wide band around the plunging end of the anticline. West of Bamford, on the north side of the anticline, only a thin band of the shale has been observed. Beyond Marietta Junction the shale on the north side of the anticline is faulted out. The Kinzers formation makes small ridges in the four triangular fault blocks south of Salunga and a larger ridge south of Landisville. Several short hills of shale occur northwest and northeast of Fruitville in the Fruitville anticlinal horst, and longer curving hills of shale lie in the fault block north of Shreiner."

"The Kinzers formation (6 p. 52) in the McCalls Ferry-Quarryville district occurs in two synclinal folds in the Vintage dolomite 2 miles north of Gap."

"The Kinzers formation (3, pp. 11-12) is exposed in the southern part of the New Holland quadrangle, where it forms narrow ridges separating the valleys underlain by Vintage dolomite from the valley areas of Ledger dolomite. The most conspicuous ridges extend northeast of Weavertown, south of Ledger, and from Leaman Place to Buyerstown and eastward. The Kinzers formation occurs also in small anticlinal hills surrounded by Ledger dolomite."

Ledger dolomite. "The Ledger dolomite (4, p. 31), which overlies the Kinzers formation, is the upper formation of the Lower Cambrian calcareous series. It is in general a massive-bedded sparkling white or light-gray coarse-grained dolomite, in part mottled by fine dark-gray spots. A few beds are dark gray; others are dark blue; a little is fine grained. In general it is a very pure dolomite, but near the middle there are siliceous or cherty beds which weather to irregular pitted ferruginous chert. It is so massively bedded that bedding planes are seldom seen except in the upper layers, which are thinner and better bedded. It weathers to a dark granular crumbly surface and forms a characteristic deep-red granular clay soil which in places contains rough ferruginous chert.

"The dolomite weathers so readily that it is nearly everywhere covered by the deep red soil and has few rock outcrops. Its character is best observed in quarries, such as the Bellemont quarry, 2 miles north of Lancaster, and the Dolomite Products Co. quarry, at Shreiner. Good exposures may also be seen in the railroad cuts south of Dillerville, where some of the rock appears to be nearly a pure calcium limestone. The high-calcium limestone in the large quarries in the vicinity of York and Hanover is in the Ledger formation, and from a study of the rock in these quarries the writers have concluded that the original rock was a pure high-calcium limestone which in most places has been altered to dolomite by the replacement of some of the calcium by magnesium. This accounts for the coarse character of the dolomite and the general lack of bedding planes.

"As exposures of the formation are rare, and the bedding of the dolomite difficult to determine, the thickness of the formation can not be measured. It is estimated to be about 1,000 feet."

"The largest area of the formation in the Lancaster quadrangle lies just north of Lancaster, where it is about 1½ miles wide. This wide belt extends from the east edge of the quadrangle to Dillerville and thence northward to Fruitville, comprising some of the richest farm land in the quadrangle. The formation also extends eastward on the north side of the Eden syncline nearly to the east edge of the

quadrangle. It extends westward in a narrower belt to Landisville, but with some interruptions due to faulting. A small elongated area lies north of Chestnut Hill near Farmdale, and a narrow belt disjointed by faults lies between the line of hills of Kinzers formation and Conestoga limestone south of Chestnut Hill, extending from Rohrerstown to Columbia."

"It occupies wide valleys (3, p. 12) in the southern half of the New Holland quadrangle, south of Goodville, New Holland, and Mechanicsburg."

Elbrook limestone. "The Elbook (4, p. 32) is in general a finely laminated, very fine-grained dove-colored to light-blue magnesian limestone with some thin argillaceous layers and cream-colored fine-grained marble with white sericitic partings. It weathers to buff-colored shaly limestone and finally breaks up into thin platy fragments of buff tripoli in light sandy soil, contrasting strongly with the red clay soil of the Ledger. It gives rise to low hills that stand above the level of the dolomite lowland. The formation is generally so deeply weathered that the details of its character and thickness can not be determined. Its best exposures in the quadrangle are along Conestoga Creek at Binkley and for a mile to the south. From observed dips and width of outcrop it is estimated to be about 1,000 feet thick."

"The Elbrook limestone occurs in the Eden syncline in the vicinity of Roseville, Binkley, and Eden; in two areas north of the syncline—one near Fruitville and the other at Hunsecker (just east of this quadrangle); in a long area from Landisville through East Petersburg nearly to Oregon; and in an anticlinal area 1 mile north of Neffsville. In the Marietta anticline, in the western part of the Lancaster quadrangle and in the adjacent Middletown quadrangle, it is not recognizable between the Ledger dolomite and the Conococheague limestone but its apparent absence may be due to a change in lithology, chiefly the appearance of dark limestone and dolomite interbedded with white marble, resembling the Conococheague limestone."

"The Elbrook limestone (3, p. 12) occurs in two areas (in the New Holland quadrangle) surrounded by the Ledger dolomite, extending from the western edge of the quadrangle nearly to Red Well School, and in an area north of the Ledger dolomite from Mechanicsburg east through Bareville, New Holland and Goodville. The Elbrook limestone of these areas forms low ridges which rise above the valley country underlain by adjoining Ledger dolomite and the Conococheague limestone."

Conococheague limestone. "The Conococheague limestone (4, pp. 33-34) overlies the Elbrook limestone without observable unconformity. It is made up of an alternation of impure thick-bedded glistening dark-blue limestone, with bands of black chert, lenticular knotty and impure dolomite, light-gray impure limestone, and white to light-gray fine-grained laminated marble. The dolomitic beds weather rough and knotty, and the argillaceous limestones weather to a banded rock in which siliceous layers stand out in relief as a network.

"A banded calcareous sandstone or chert generally occurs at the base of the formation and gives rise to residual sandstone fragments in the soil. The formation contains thick layers of thick-bedded light-gray fine-grained marble, which are *Cryptozoon* reefs. There are gen-

erally present also thin-bedded wavy limestones probably of related organic origin. Such reef-bearing beds are well exposed on Chickies Creek northwest of Farmdale and in the quarry 1½ miles northwest of Neffsville. The rhythmic occurrence of these reefs, suggesting seasonal growth, is well shown * * * at this quarry."

"The miscellaneous character of the beds composing the formation is well shown in the railroad cut at Salunga, in a quarry beside the Harrisburg road north of Chickies Creek, in quarries and stream cuts on Chickies Creek in the vicinity of Centerville, and by the following detailed section in a quarry in the New Holland quadrangle:

Section showing variable character of Conococheague limestone, Kurtz quarry, 1 mile southwest of Ephrata

	Feet
Yellow earthy-weathering fine-grained wavy-bedded magnesian marble, nodular at base	10
Light-gray fine-grained marble, laminated with magnesian layers, weathering buff and finely crinkly	4
White saccharoidal marble	1
Fine-grained magnesian limestone, weathering buff	3
Fine-grained mottled white marble, banded with drab and somewhat magnesian	4
Dark argillaceous fine-grained limestone, weathering with buff banding	3
Shaly magnesian limestone with black carbonaceous seams	2
Dark and light gray banded fine-grained marble, weathering buff banded and ribbed, to earthy buff tripoli	4
White and gray mottled fine-grained marble, weathering cavernous	3
Massive dark dolomite; no bedding planes	8
Light-gray fine-grained marble, mottled with dark gray, in part laminated with earthy layers	6
Massive black dolomite; no bedding planes	8
Thin-bedded dark dolomite	5
Black hackly hard siliceous dolomite, veined with calcite; no bedding planes	20

"The formation weathers to light-yellow sandy soil containing many shaly and sandy fragments and white quartz and consequently makes low hills which rise above the limestone lowland. The formation is much folded, and exposures are so poor that the thickness can not be measured, but it is estimated to be about 1,000 feet."

"The Conococheague limestone (4, p. 36) covers a large hilly area around Centerville, north of Chestnut Hill, and extends eastward to Oregon, making the higher land with yellow sandy soil northwest and north of East Petersburg and north of Neffsville. Another wide area is exposed in the Lititz anticline from Limerock to the east edge of the Lancaster quadrangle. A small area is mapped northwest of Roseville, and another at Eden."

"It occurs in a small area (3, p. 13) surrounded by the Elbrook limestone on the western edge of the (New Holland) quadrangle south of Hunsecker, and in a band 2 to 3 miles wide which extends across the central part of the quadrangle. Another area lies north of the Ephrata-Akron hills and passes northward under Beekmantown limestone as does the central area."

Beekmantown limestone. "The Beekmantown limestone (4, pp. 37-38) overlies the Conococheague. In the main it consists of finely laminated magnesian limestone, light-blue pure limestone with some fine argillaceous banding, and dark-blue lenticular dolomite much

broken and recemented by white calcite. There are also beds of white marble near the base. The blue limestone, which has in general a lighter-blue color than the Conococheague limestone, weathers to a pale-blue, light-gray, or chalky white surface on which the fine laminae partings are well brought out. The exposures are too poor to permit the measurement of a detailed section. Its thickness is estimated to be 2,000 feet.

"In the vicinity of Mount Joy the lower part of the formation contains a considerable thickness of white saccharoidal high-calcium marble, with sericite on the partings, interbedded with pure light-blue limestone. The upper part of the formation is exposed in numerous quarries in the vicinity of Manheim and west of Clay, where beds of dark dolomite occur above the pure limestone. In the quarry southwest of Manheim the uppermost beds of the formation consist of buff-weathering dark dolomite 20 feet thick, in which fossils of the *Turritoma* zone have been found, underlain by 25 feet of dark and light mottled limestone with magnesian laminations, and this in turn by thick light-blue fossiliferous pure limestone.

"South of Sporting Hill the following section of beds at about the same horizon is exposed in a quarry:

Section of part of Beekmantown limestone in Kauffman quarry

	Feet
Dark-blue and black limestone, weathering finely and irregularly laminated	30
Light-gray mottled with dark-gray limestone, weathering laminated; gastropods in granular limestone at top	30
Mostly dove-colored fine-grained, finely laminated marble, and white and dove colored spotted limestone	25
Dark limestone banded with ½-inch magnesian layers which weather buff and stand in relief; black nodular flint, weathering yellow, near base	45

"The Beekmantown limestone weathers to deep reddish soil with few natural outcrops and underlies a country of low relief between the hills made by the Cocalico shale and the low hills of the Conococheague limestone."

"The Beekmantown limestone occupies a belt 1 to 2 miles wide across the Lancaster quadrangle south of the shale ridge that extends from Sporting Hill to Kissel Hill. A branch from this belt forms the lowland around Manheim and eastward to Lititz Run. East of the shale hill at Lexington there is another area of the formation. At the west edge of the Lancaster quadrangle, north of Mount Joy, the Beekmantown limestone occupies valleys back of the shale front, and west of Sporting Hill there is a small inlier of limestone within the shale area."

"The Beekmantown limestone (3, pp. 13-14) * * * occurs in three main areas in the New Holland quadrangle,—one south of Spring Grove, another larger one southwest from Hahnstown to Brownstown and the third, southwest of Denver."

Conestoga limestone. "The Conestoga limestone (4, pp. 42-44), a formation also of Ordovician age, is present only in the southern part of the Lancaster quadrangle. It is made up chiefly of thin-bedded dark-blue argillaceous limestone and thicker-bedded blue to light-gray granular limestone with thin argillaceous partings, generally closely plicated with beds of dark graphitic shale or slate and coarse con-

glomerate or breccia of blue limestone and white marble fragments in a dark argillaceous calcareous matrix near the base of the formation. This limestone conglomerate occurs in beds as much as 10 feet thick, interbedded with slaty blue limestone and dark argillaceous dolomite. The conglomerate is well exposed in the quarries north of the Lancaster City waterworks, and at the stone quarry east of Columbia, and single beds of conglomerate may be seen at many other places near the base of the formation. A band of black graphitic slate occurs at or near the base in the southwestern part of the quadrangle and has been separately mapped. North of the Manor Hills the basal beds have also been mapped, and are dark-banded buff earthy sandstone and blue hackly shale containing pyrite cubes which weather out leaving rusty holes. This basal member becomes more prominent west of the Susquehanna, where it forms a line of low hills in most places. In the southeastern part of the quadrangle, apparently near the base of the formation, there are thick beds of light-gray granular limestone so full of round quartz grains that the rock weathers to a crumbly sandstone which is worked for building sand. These beds have also been mapped where observed. The thin-bedded limestones of the formation are generally tightly folded and veined with calcite.

"The thickness of the formation can not be determined because of its closely folded character. It is probably more than 1,000 feet thick."

"The Conestoga limestone covers all of the area south of Lancaster, Rohrerstown, and Donnerville, with small outlying areas north of Lancaster, at Dillerville, and north of Rohrerstown. West of Donnerville, it occupies the syncline between the uplifts of Cambrian quartzite in the Manor Hills and Mountville Hill. It also forms the valley around Columbia, where its basal sandy and slaty member is mappable."

It is practically the only limestone lying south of an east-west line passing through Lancaster. It also floors the narrow valley extending eastward from Quarryville to the Chester County line.

DESCRIPTION BY DISTRICTS

With the large number of quarries that have been opened in Lancaster County, it is obvious that all could not be visited in the field investigations, nor could space in this volume be given for descriptions of each operation. Those that are described will indicate sufficiently the character of limestone obtainable within the county. A number of the descriptions are quoted directly from the publications of Stose, Jonas, and Knopf (see bibliography at close of chapter).

Billmeyer Area. The J. E. Baker Co. is working 2 large quarries at Billmeyer, close to Susquehanna River. The large one which lies just north of the town has been extensively worked and is now more than 200 feet deep at the highest point. The dolomite is mainly a gray, crystalline, compact rock although some layers are dense and dark blue. Interbedded with the good dolomite which is low in silica, there are a few siliceous beds. Loading is by hand in order to eliminate the poor stone. The good stone is burned for lime and the siliceous stone and small sizes of both grades are used for crushed stone.

The smaller quarry, located south of the town, contains high grade limestone, low in both silica and magnesia. Part is a soft, white,

crystalline rock and part a rather dark blue color. Most of the high-calcium stone is burned to make high-calcium lime, some of which has been used in the manufacture of soap and glass. Part of the same type of stone has been pulverized for use in the manufacture of plate glass, as asphalt filler, and for agricultural uses.

When visited in 1921, the company had 51 ordinary upright lime kilns, 2 125-foot rotary kilns, 7 flame kilns and 2 pot kilns. A more recent statement gives 27 shaft and rotary kilns as the equipment. The hydrating plant at this high-calcium stone quarry, which was burned a few years ago, has been rebuilt.

Rheems-Florin-Mount Joy Area. On the Miller farm, one mile northwest of Florin, there is a fine exposure of Beekmantown limestone consisting of interbedded low and high magnesian layers. The high-calcium beds weather to a chalky white and make such an impressive appearance that the materials were thought to be suitable for the manufacture of Portland cement. Shale from the Cocalico formation nearby was to have been used to mix with the high grade limestone. Careful investigation showed the presence of so much interbedded dolomite that it was not regarded as feasible to make Portland cement and the project was abandoned. The accompanying diagrams, representing part of the data obtained in the investigations, show the variations in chemical composition. It is possible that in some places the Beekmantown may include sufficient high grade limestone not so badly mixed with dolomite beds as to prevent its use for Portland cement, but no such locality is known. Certainly any company planning to develop a quarry for such a purpose should use great care in prospecting the property.

The Penn Lime and Stone Co. at Rheems has been quarrying Beekmantown limestone for a number of years and the openings are large but not deep. Limestone has been burned here but in recent years the entire output has been crushed stone. There are some interbedded layers of high-calcium limestone, although most of it is highly magnesian and some beds also high in silica. The stone is mainly dark colored although some layers are light gray. It is hard and tough and thus well suited for crushed stone. The strata are intricately folded with overturned anticlines and synclines. There are many veins of calcite and quartz. In some a beautiful variety of salmon-colored calcite is conspicuous.

Jacob Strickler in 1930 was working a quarry for crushed stone on Donegal Creek about 3 miles south of Mount Joy. The quarry was once worked for lime and the old kilns are still standing. The stone is very hard and high in magnesia and silica. It breaks into angular blocks. Probably it belongs to the Conococheague formation. The clay overburden is heavy. The capacity of the quarry is about 100 tons per day. The main product is used on the highways and the fines for concrete blocks.

From a small quarry nearby at one time the Mount Joy Magnesia Co. with its plant in Mount Joy obtained dolomite for the extraction of magnesia. It did not prove entirely satisfactory so that stone was shipped in from Chester County. The company later went into bankruptcy.

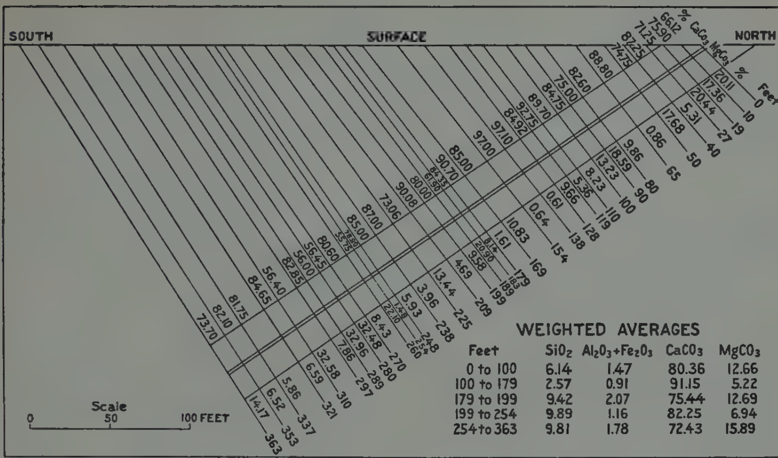


Fig. 18. Diagram of drill hole No. 1, Miller farm, Florin.

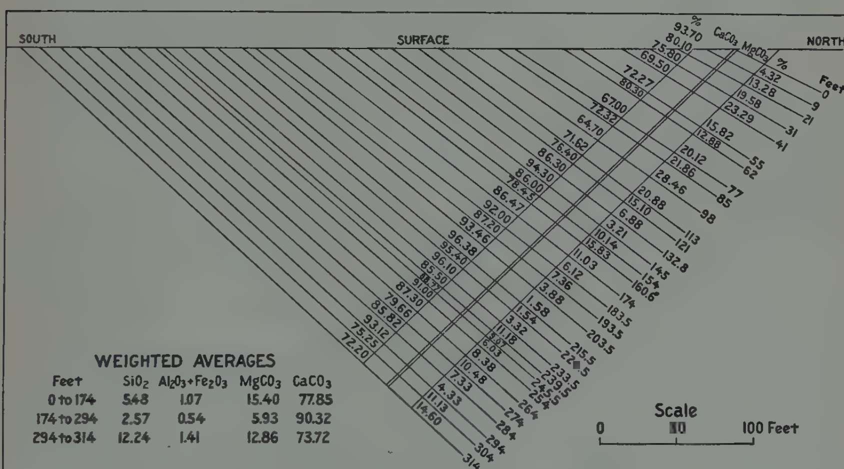


Fig. 19. Diagram of drill hole No. 2, Miller farm, Florin.

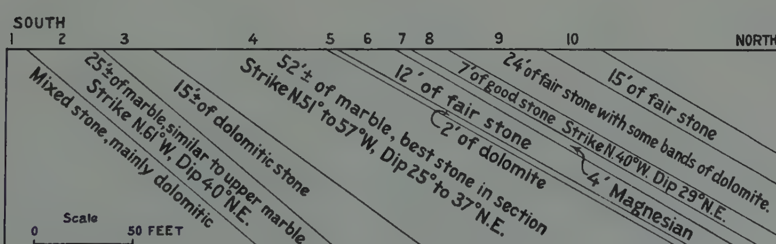


Fig. 20. Diagram of trench section, Miller farm, Florin.

About a mile south of the Strickler quarry near Chickies Station, there is a large dolomite quarry, now abandoned. It is said that much of the product was used for flux.

"There are many quarries in the Beekmantown limestone near Mount Joy which are no longer operating. One of the active quarries is that of J. N. Stauffer & Bro., R. D. 2, Mount Joy, on Little Chickies Creek 1 mile north of Mount Joy. The quarry is cut into the hill 100 feet and has a 60-foot face, 1,000 feet long, facing south. Horse-drawn carts haul the stone to two crushers which have pan-elevators and two large elevated bins with concrete foundation built over a loading tunnel. A third crusher with pan-elevators and bins is used on emergency when the quarry is working to capacity."

Centerville Area. N. S. Newcomer & Son is working a quarry in the side of a hill on the left bank of Chickies Creek at Centerville. The length of the opening is about 200 feet and the working face about 45 feet high. The quarry contains interbedded low and high magnesia stone of a blue color with many calcite veins. The rock belongs to the Conococheague formation. At one time some of the stone was pulverized for agricultural use but recently the entire product has been crushed stone. The capacity is 60 to 80 tons daily.

About half a mile east of the Newcomer quarry is the quarry of A. M. Eshleman opened in 1922. It is in the Conococheague formation. It contains a variety of stone. At the south side, there is a band of light buff dolomite. The remainder consists of interbedded high and low magnesian layers. There are numerous veins of calcite and quartz. The clay pockets are bad. The product is almost entirely crushed stone although some building stone has been produced. In 1930 the daily capacity was 200 tons but it was planned to increase it to 500 tons.

"Another small quarry (4, p. 75) in Conococheague limestone in the same vicinity is operated by I. S. Siegrist, of Columbia. The quarry is south of Farmdale, in dark-blue argillaceous dolomite, and was idle in 1925."

Manheim-Sporting Hill Area. Just north of Manheim is the quarry of C. B. Winters which was opened in 1921. From this quarry was obtained the stone for the State road from Manheim to the Lebanon County line. The quarry is opened in Beekmantown limestone close to the contact with the overlying Cocalico shale. The stone is mainly highly magnesian, but there are some interbedded low magnesian strata. The beds are regular with an average strike of N68°E., dip 84°SE. The overburden ranges from 2 to 4 feet in thickness. There are a few clay pockets. Some lime has been burned here but the main product is crushed stone for highways and concrete. The capacity of the plant is about 150 tons per day.

About half a mile east of the Winters quarry, Harry E. Gantz is operating in a small way in an old quarry, now largely filled with water, to obtain stone for occasional burning. He has 3 stone kilns. The stone belongs to the Beekmantown formation and consists of high lime and magnesian rocks interbedded. Most of the stone used is of the low magnesian variety. The strata dip steeply to the southeast.

Another "quarry (4, p. 71) is south of the road to Sporting Hill, west of Chickies Creek. It is owned by A. F. Metzgar, of Manheim.

After it had been idle for several months in 1925, a new face was prepared by stripping 10 to 20 feet of shale from the north end of the quarry. The old face was 60 feet above the water surface in a hole filled by water. The rock is a hard, well-bedded blue limestone and dolomite with argillaceous partings, dipping 15°SW. under the shale. The quarry is equipped with crusher and bins, with tram and cable to carry the rock to the crusher. Electric power is used. The product is crushed stone which is delivered by truck.

"The J. L. Kauffman quarry lies half a mile south of the Cocalico shale area at Sporting Hill. The quarry has three stone kilns, but lime has not been burned recently. A considerable area has been stripped, and the quarry face is about 20 feet high, exposing a thickness of 100 feet of beds that dip 80°N. The upper 30 feet consists of blue limestone and light-colored dolomite, containing gastropods of upper Beekmantown age. Below it there is 25 feet of white and dove-colored fine-grained marble overlying 45 feet of limestone in which banding shows on weathering. The fine-grained marble and blue limestone are high in calcium and would produce high-grade lime. This quarry has a crusher, pan-elevator, and bins, and a hydrating plant may be installed." Nine samples taken over a width of 130 feet across the quarry showed the following composition: $CaCO_3$, 93.25%; $MgCO_3$, 5.52%; $Fe_2O_3 + Al_2O_3$, .60%; SiO_2, 1.30%.

Lititz Area. A number of limestone quarries have been worked in the Conococheague formation mainly in the vicinity of Lititz and Limerock. These have furnished stone for lime and crushed stone.

"At Limerock (4, p. 70), 2 miles west of Lititz, there is a large quarry south of the Philadelphia & Reading Railroad. It was formerly worked by the Ramoth Lime & Stone Co., of Lebanon, but is now run by J. D. Bucher. The quarry is equipped with two crushers and a pulverizer. Some lime is burned. The equipment was operated by steam until 1925, when an electric motor was installed which uses power furnished by the Edison Electric Co., of Lancaster. The quarry is 200 feet long parallel to the strike, east and west, and about 100 feet across the strike, with a 30-foot operating face. The rock is hard blue to gray limestone which dips 20°S. The blasted rock is loaded into iron tramcars, which are drawn by cable to the crusher. Another quarry, about 100 feet square, now idle, lies to the east of the active quarry."

Theodore L. Forney operates a quarry just north of Lititz. The stone is mainly blue and highly magnesian, in places shattered, and with numerous calcite veins. Some of the vein calcite is pink. There are some layers of low-magnesian limestone of good quality. On the weathered surfaces there is a peculiar blotched appearance that is caused by the differences in the amount of magnesia. This is usually characteristic of the Beekmantown. The quarry face is about 25 feet high. The strata dip gently to the south in the direction in which the quarry is being advanced. The stripping ranges from 3 to 8 feet and there are some bad clay pockets that extend downward to the floor of the quarry.

A mile west of Lititz is a small quarry in the Conococheague formation that has been worked by Albert Shenk.

Binkley Bros. and Ober, who also operate elsewhere in the county, have a quarry one mile southeast of Lititz that exposes interbedded low and high magnesian strata with some shaly material. Some of the beds are much folded. All of the material quarried is crushed. The daily capacity is about 300 tons.

Brunnerville-Clay Area. A "quarry (4, p. 68) is located 1 mile west of Clay, in the valley of Beekmantown limestone bordered by Cocalico shale. It is worked by Isaac Stauffer. The rock is dense blue limestone, which dips 55°NE. and furnishes good crushed stone for road material.

"Two other quarries are operated in the same valley. C. P. Risser's quarry lies a mile south of the Isaac Stauffer quarry and north of Hammer Creek. It is operated by Anderson Shoemaker of Lititz and is equipped with a small jaw crusher, screens and bins, and scale. The crushed stone is marketed by wagon. A mile to the south of this quarry is that of John Seibert, which is worked occasionally for crushed stone."

East Petersburg-Neffsville Area. Binkley and Ober have been working dolomitic stone in the Conococheague formation less than a mile north of East Petersburg for several years. The quarry is about 250 feet in diameter with a 25-foot face but they plan to sink 50 feet deeper. They also plan to enlarge the area of the quarry and had an additional area stripped when visited in 1930. The main rock is dark blue and highly magnesian. The beds vary from thin to massive. Even the apparently massive beds break into thin layers on weathering. There is a band of light-colored dolomite in the part of the section that is attractive in appearance and might be used for buildings. One bed consists of a gnarly, low-magnesian rock with kernels of calcite and considerable sericite. The strata strike N73°E. and dip 12°NW. on an average. In a few places the dip is considerably steeper. The entire product of the quarry is crushed stone, most of which has been used on the highways.

Thomas H. Erb works a small quarry in the Beekmantown limestone 1½ miles southeast of Fairland. The quarry was formerly worked entirely for stone for lime but more recently the bulk of the stone has been crushed for road metal. He has a crusher capable of producing 80 tons a day. There are 2 kilns on the property and occasionally some stone is burned. The main stone in the quarry is a dark blue, dense dolomite which breaks into irregular pieces and is used solely for crushed stone. Interbedded with the dolomite there are two varieties of high-calcium stone that produce good lime. One is a coarsely crystalline blue stone that gives out a fetid odor when struck. It varies from 2 to 6 feet in thickness. This yields a fine grade lump lime that is said to be especially fine to add to the mixture used for spraying potato plants against blight. The other is a dove-colored limestone that breaks with a glassy fracture and yields a good grade of lime, but less lump. It varies in thickness up to 5 feet. In working the quarry the blocks of stone best adapted for lime are put aside and burned from time to time.

Abraham E. Binkley opened a quarry in 1925 about 2½ miles northeast of Neffsville in the upper part of the Conococheague formation. There is some low magnesian rock in the quarry, although most

of it is dolomitic. Several different varieties can be noted varying in color from gray to blue and breaking in different ways. Nearly all the stone produced is crushed for highways and concrete, although some attractive building stone has been sorted out for the construction of foundations, walls, and residences.

Columbia Area. Extensive quarrying has been done in several places east and southeast of Columbia. In recent years the principal quarry in operation has been that of Clarence D. Stoner, located along a branch of Strickler Run, about a mile east of Columbia. The quarry is a large one, over 500 feet in diameter. Crushed stone alone is mainly produced but also some building stone. The capacity is 250 tons daily, but will be increased by the erection of new bins. At the south end of the quarry there is a badly crumpled dark blue, thin-bedded, dolomitic limestone. Overlying it is a great thickness of limestone of conglomeratic character. The fragments show well on weathered surfaces but are also visible on fresh fractures. This stone is rather low in magnesia. The conglomerate beds are crumpled but in general dip steeply to the north. Overlying the conglomerate unconformably are some black shaly strata dipping gently to the north. This rock must be discarded. The stone from this quarry has been used extensively on the highways. The quarry is said to have been opened more than 50 years ago.

Lancaster Area. As the city of Lancaster is so much the most important town in the county, it is natural that there should be many limestone quarries in that vicinity. Limestones are readily accessible and quarries have been worked in all directions from the city. Most are along Conestoga or Little Conestoga creeks. The quarries to the north of the city are in the Ledger dolomite and those to the south, west, and east in the Conestoga limestone.

"The Bellemont quarry (4, p. 75) (in the Ledger dolomite) 1 mile north of Lancaster is owned by Aaron B. Hess, of Harrisburg, and was operated by J. C. Budding before 1923 for crushed stone and lime. The quarry is 800 by 400 feet and has a 20-foot face above the water that fills the hole. The rock is a white and blue mottled dolomite and has been analyzed by the Bethlehem Steel Co. It is a dolomite with a little silica and closely resembles in composition the Ledger dolomite in the area near Newtown, as is shown in the table of analyses.

"The quarry of the Dolomite Products Co., near Shreiner station, is in the same formation—typical Ledger dolomite. The company, whose address is Brenneman Building, North Duke Street, Lancaster, formerly operated this quarry for the manufacture of magnesium products and equipped it with large buildings and machinery, which are now abandoned and falling into decay. A spur of the Philadelphia & Reading Railroad runs into the plant.

"Another abandoned quarry in the Ledger dolomite is 3 miles west of Shreiner, near the former lead and zinc mines at Bamford. This quarry was operated by the J. E. Baker Co. for high-magnesia fluxing stone, but it has been abandoned in favor of this company's large quarry at Billmeyer, on Susquehanna River, which produces better fluxing stone at a lower cost."

"The West End quarry (4, p. 79) one mile west of Lancaster, is on the east side of Little Conestoga Creek south of the Lincoln Highway and has been operated by Clarence D. Stoner for a number of years. The rock is thin-bedded, closely folded slaty blue limestone veined with white calcite and is taken out of the main opening, which extends 200 feet eastward into the hill, in an oval 300 feet across the strike. Quarrying has not cut down below the creek level, and horse-drawn carts haul the quarried rock to the crushing plant on the west side of the creek. The crushed stone is shipped by truck. J. C. Budding, of Lancaster, is agent for the stone."

"Charles S. Bender, of Millersville, operates a quarry on Little Conestoga Creek 1 mile west of Millersville, near Frantz Mill. The rock is blue crystalline limestone of the Conestoga. It is closely folded, thin-bedded, with thin graphitic slaty partings, and infolded with thick-bedded siliceous crystalline limestone. The quarry face is 30 feet high and 100 feet long on the strike and is in a hill on the west side of Little Conestoga Creek. It lies east of an older quarry operated for four or five years by Mr. Bender before he opened the present quarry. The old quarry supplied crushed stone for the Millersville-Lancaster road. The present quarry produces crushed stone in four grades. The product is sorted and the graphitic shaly material is eliminated by hand after crushing and screening. The equipment consist of a No. 4 Champion crusher, pan-elevator, and bins. A Fordson tractor supplies power for running the Schramm air compressor and rock drill. The product is shipped by truck for highway work."

Clarence D. Stoner works a quarry just northeast of Lancaster close to the waterworks. The quarry is about 200 feet long with a face about 35 feet in height. A low anticlinal fold is shown in the quarry. Two kinds of stone are prominently developed. The principal one is a gnarly, massive, blue, siliceous dolomite that is very tough and does not have any pronounced lines of fracture. Some of the beds are as much as 10 feet thick. In primary blasting it produces many large blocks that must be broken by secondary shooting. The other prominent type of rock is a black shaly rock containing considerable pyrite in crystals. Near the surface this breaks into small layers and must be discarded. There is also some limestone low in magnesia. The overburden of clay varies from 4 to 6 feet. One bad clay pocket extending to the floor of the quarry was noted. The capacity of the quarry is 400 to 500 tons of crushed stone daily.

"The Conestoga Traction Co. (4, p. 77) operates at intervals an old quarry north of the C. D. Stoner quarry. It is in ribbed and banded Conestoga limestone and is used for crushed stone. This quarry furnished the blocks for the piers of the Pennsylvania Railroad bridge over Conestoga Creek just south of the Lancaster waterworks. These blocks are 5 by 2 by 1½ feet and are built into a four-arch stone bridge. Blocks of this ribbed stone were used by the railroad in retaining walls at the Pennsylvania Railroad station at Lancaster and in bridges and culverts in and around the city. Churches and other buildings have also been built of this strikingly marked stone."

John B. Heidig operates a quarry in the Conestoga limestone in the east part of Lancaster, a short distance west of Conestoga Creek. The quarry covers a large area but nowhere has a greater thickness

than 25 feet been worked. Water bothers when the quarry is worked lower. The beds have been folded so that they dip in entirely different directions in different parts of the quarry. In general the dips are steep. There are several different kinds of stone in the quarry, such as massive, gray, siliceous and magnesian beds; thin-bedded, blue, hard, siliceous limestone with shale partings, gray, low-magnesian stone, shaly limestone, etc. Nearby is an outcrop of conglomeratic marble where a quarry has been planned. There are occasional calcite veins some of which contain some fluorite. The quarry has been worked for more than 20 years. The greater part of the stone has been used for building stone in most years. The poorer stone and the refuse have been crushed. About 80 tons daily go to the crusher.

"A new opening (4, p. 89) for building stone is the Walter B. Kendig quarry just east of Lancaster and south of J. B. Heidig crushed stone quarry. The rock is Conestoga limestone of the banded blue crystalline type with slickensided slaty partings. It strikes N60°E. and dips 75°S. Blocks have been taken out from an opening about 25 feet square. The quarry has a drilling machine and a gasoline pump for removing water. The slabs are used for buildings in Lancaster.

"The northerly quarry at the old City Hall has been operated by J. D. Kendig for building blocks and for crushed stone. The rock is the Conestoga limestone. During 1925 the quarry supplied building stone for two houses in Lancaster. The quarry is now operated by J. M. Brenner. It supplied stone for the old City Mill and adjoining houses. The old Factory Bridge over Conestoga Creek, 1½ miles to the south, is also built of Conestoga limestone of similar type and is typical of the older stone bridges of the region." The rock is a micaceous crystalline limestone with numerous laminae of black shale. Some layers are free from shale and micaceous matter and are composed of coarsely crystalline gray marble. Some layers are decidedly conglomeratic. The strata are crumpled and faulted but in general dip steeply to the south. In 1930 the quarry was being worked for crushed stone only. In working for this purpose, care must be taken that not too much of the shaly material is obtained. The quarry is a large one and has a quarry face as much as 80 feet in height in places. The capacity is about 225 tons of crushed stone daily.

"The Conestoga Traction Co. (4, pp. 77-79) owns a quarry along its line to Rocky Springs Park in an oxbow of Conestoga Creek southeast of Lancaster. There are two openings, the southern one in blue crystalline limestone in beds 3 to 6 feet thick and the northern one in hard siliceous thick-bedded dolomite. A crusher, pan-elevator, screens and bins are located at the northern quarry. The southern quarry has a face 30 feet high and 30 feet wide and is cut into the hill about 40 feet. It is worked by hand, and the large blocks taken out are loaded on tram-cars and hauled up an incline to the crusher.

"Two active quarries on the east side of the Rocky Springs oxbow, west of an old mill dam on property owned by Martha Davis, are called the City Mill quarries. The smaller quarry, which lies to the north, has been operated by J. D. Kendig for building stone, and the southern quarry has been worked for crushed stone. The J. W. Brenner Co., R. D. 6, Lancaster, is operating these quarries and has installed a crusher, pan-elevator, screens, and bins at the northern

quarry. Rock is hauled from the southern quarry to the crusher in three Ford trucks. The crusher is a Champion jaw crusher, No. 4½, and the entire equipment is run by electric motors installed in 1925. The southern quarry is 1,000 feet long from north to south and is cut 50 to 75 feet westward into the hill, with a 40-foot face. The rock is siliceous limestone in beds 3 to 6-feet thick, infolded with slaty limestone, and is quarried for crushed stone.

"The quarry of Denlinger & Johnson, 61 North Duke Street, Lancaster, lies west of Conestoga Creek and just within the Lancaster city limits. It is 200 feet long and has a face 25 feet high on the west side. It is in closely folded thin slaty limestone. Horse-drawn carts haul the stone to the crusher, a Champion No. 4. The quarry is equipped also with pan-elevator and three screens and bins, operated by steam. The product is made into four sizes and is used for road material and concrete."

Brenner and Heistand reopened an old quarry formerly worked for burning lime about 1922 and are now producing crushed stone only. The quarry is on the west side of Conestoga Creek about a mile south of Lancaster. Throughout most of the quarry the strata are practically vertical with an east-west strike. Considerable close folding is to be seen. The major portion of the rock is hard and tough and probably high in silica and low in magnesia. It contains many veins of calcite and quartz. Interbedded with the hard rock are bands of soft micaceous limestone in which there are numerous cubes of pyrite. This rock must be discarded. Clay pockets are bad and at one time a small open cave was encountered. The quarry is being advanced toward the west, along the strike, into the hill. It is about 125 feet wide, 500 feet long, with a working face 45 to 68 feet in height. The stone is loaded by steam shovel. Occasional loads are discarded if they contain much rotten micaceous rock or dirt. Also some poor stone is picked out at the crusher. The daily capacity is about 125 tons of crushed stone.

About 1 mile west of Millersville, H. R. Miller operates a quarry formerly worked for lime but now producing crushed stone and building stone. The building stone is mainly for foundations. The rock is almost entirely micaceous limestone but there is one band about 20 feet thick of hard tough stone with practically no mica. This stone is probably siliceous. It contains many calcite veins. There are numerous pyrite cubes in the micaceous limestone. Because of considerable clay and rotten stone near the surface the stone must be loaded by hand. The quarry face is about 150 feet long and 70 feet high. The capacity of the plant is 150 to 200 tons per day.

Washingtonboro Area. There has not been much limestone quarrying in the Washingtonboro region recently. In 1930 the only quarry in operation was that of Brenner and Heistand about 1½ miles southeast of Washingtonboro. The stone is the micaceous limestone of the Conestoga formation. It is a high grade gray crystalline rock with micaceous laminations along which it breaks. On looking at the broken surface of the rock it appears to be a mica schist but on looking at the ends of the blocks it seems to be a coarsely crystalline marble. The strata are considerably crumpled, but in general they dip to the northwest at angles of 20° to 30°. The stone is satisfactory for

crushed stone, for which purpose it is quarried, except near the outcrop where it is rotten. Considerable clay is present.

Strassburg Area. Several limestone quarries have been opened along Pequea Creek west of Strassburg, all in the Conestoga limestone. Aldus Zittle and Bro. work a quarry about 1½ miles west of Strassburg. The quarry is about 150 feet long, 60 feet wide, and 40 feet high at highest point. The quarry is advanced eastward along the strike of the beds. The stone worked is a gray, coarsely crystalline marble with interlaminated micaceous streaks along which the stone breaks. This type of stone contains layers in which very little mica can be noted. Near the surface the stone is badly weathered but is hard and solid lower down. From 5 to 10 feet of the surficial stone must be discarded. At one time, lime was burned here but the present operation is entirely for crushed stone. At times building stone is sold. The capacity of the plant is about 150 tons daily.

The Lampeter Township quarry is located about a mile southeast of Lampeter. This new quarry is about 175 feet long, advancing westward along the strike, 75 feet wide, and about 45 feet high at highest point. The stone is similar to that in the Zittle quarry. The micaceous or schistose character of the stone is pronounced except in the southwest corner, where it is much more solid. The soil overburden is light, but the stone is badly disintegrated to the depth of 10 to 12 feet. The capacity of the plant is about 100 tons per day, and the output is used on the township roads.

An abandoned quarry formerly worked by Lampeter Township is located on the west bank of Pequea Creek about 300 yards east of the active quarry.

Paradise-Leaman Place-Kinzers Area. In the vicinity of Bellemont, there are some extensive abandoned quarries where limestone was dug and burned. In recent years J. L. Denlinger has operated a quarry about 1½ miles south of Leaman Place. He reopened an old quarry about 1921, and crushes nearly all the good stone but also gets out some building stone. There are 2 old kilns on the property. The stone is in the Conestoga formation. Several varieties are interbedded—dark-colored, hard, siliceous and perhaps also high-magnesian stone, softer, light-colored, high-calcium stone, and some micaceous limestone in which mica has developed along the bedding planes. The beds are considerably crumpled but in general are almost vertical with an approximate east-west strike. The quarry has been advanced about 600 feet along the strike. It is about 100 feet wide and the west end working face is about 40 feet high. There are 2 large crushers, one operated by electric power and one by a steam engine. The daily output is about 450 tons but the capacity is about 600 tons.

E. A. Slaymaker has operated a quarry at Kinzers in the Vintage dolomite, for the past 16 years, to obtain stone for the highways. A little building stone is also produced. At one time lime was burned in 11 kilns which were all in use. The rock is a fairly uniform, finely crystalline, gray dolomite. The beds vary in thickness from 18 inches to 10 feet. The quarry is developed along the crest and south limb of an anticlinal fold with the strike approximately east-west. The overburden of clay is 3 to 5 feet deep but below this there are clay seams so numerous that there is not much good stone until about 14 feet

from the surface. The quarry is about 600 feet long, 150 feet wide, and 50 feet deep. The capacity of the plant is about 150 tons per day.

Jacob Z. Landis is operating a quarry in the Conestoga limestone at Leaman Place. This quarry is about 250 feet by 250 feet with a 40-foot face. The output of about 80 tons per day is mainly used for crushed rock for road and bridge work. A small quantity of building stone is gotten out, and some of the rock is pulverized for local agricultural use. The rock is of several different varieties, ranging from marble to the micaceous pyritic type of rock found south of Lancaster. The micaceous stone is found in a thin-bedded band about 10 feet wide dipping about 45° to the north across the quarry face. The marble, which is white, soft, and coarsely crystalline, is not very abundant. Most of the stone is a dark grayish, coarsely crystalline material, very tough and containing considerable magnesium. That pulverized for agricultural use is advertised as averaging 96 per cent $CaCO_3$ and $MgCO_3$. Except for the layer of micaceous stone, the rock is everywhere very massive, coming out in huge chunks. Overburden is not more than 2 feet.

Lawrence May in 1930 reopened an old quarry in the north edge of Leaman Place just south of the Pennsylvania Railroad tracks. Years ago this quarry was worked for building stone and for bridges for the Pennsylvania Railroad. The present operator is producing both crushed stone and building stone. The rock belongs to the Conestoga formation. In the main, the beds are of fair thickness with a small amount of micaceous material. The stone is hard and well adapted for the purposes for which it is being used. When the plant was visited, there was only a small crusher in use but it was planned to install a larger one. The product was being used on county and township roads. The working face is about 400 feet long and 40 to 50 feet high. The quarry is being advanced southward against a gentle dip to the north.

About a mile north of Leaman Place is the old Aaron Beiler quarry in the Conestoga limestone that was once worked for lime, building stone, and crushed stone. The stone appears to be of good quality, finely crystalline, thick bedded and fairly uniform in structure. Although the strike and dip change somewhat in different parts of the quarry, the beds in general strike N. 12°W. and dip 19°SW.

The small Musser quarry on the south of the Lincoln Highway, just east of Soudersburg, formerly worked for stone for bridges, houses and other buildings in the vicinity, has been idle for many years. The rock belongs to the Conestoga formation. The quarry is in two parts,—the southern opening exposes a horizontally bedded limestone, apparently fairly high in magnesia and silica but which yields a desirable building stone and a shaly darker colored stone which dips steeply to the south. The northern opening is entirely within the latter kind of stone.

"The A. B. King quarry (3, pp. 29-30) is 1½ miles northwest of Intercourse, on the south bank of Muddy Run. The limestone is thin and thick bedded, mottled blue. It dips 70° north. The quarry is opened along the strike and stone is crushed for road material. The quarry is small and a portable crusher is brought when it is operated. An adjacent quarry is operated by J. H. Denninger. The opening is about 75 by 100 feet across and 30 feet deep in dark blue glistening

dolomite mottled with zigzag black lines. A Champion No. 4½ crusher is driven by a steam tractor. A small roll pulverizer and rotary screen complete the mechanical equipment for making fine ground limestone. These quarries and an idle one nearby are in the limestone beds of the Kinzers formation.''

''Several quarries have been opened in the Ledger dolomite in the southeastern part of the New Holland quadrangle. Three miles east of Intercourse on the north side of the old State road is a quarry once operated by R. Z. Stelfuss for ground limestone. The pit is small, and the stone was crushed by portable machinery, which has been removed in 1925. Mr. Stelfuss operated a quarry one mile west of the present quarry in a white thick-bedded dolomite used to small extent in Lancaster for building stone. The John Martin quarry is north of the road between Buyerstown and Millwood School. The rock is fine white dolomite and hard knotty dolomite.'' Part of the dolomite appears to be of excellent quality and probably low in silica.

New Providence-Quarryville Area. A number of quarries were worked in the vicinity of New Providence when lime was more generally burned for local use.

Just northwest of Quarryville is the old Orchard quarry that was opened in 1826 and has been rather extensively worked. It is within the Conestoga formation. It has furnished a large amount of stone that was burned for lime and some attractive marble for buildings, and more recently has been producing crushed stone. It contains three rather distinct types of stone—a white siliceous marble, a gray crystalline limestone, and a decidedly micaceous limestone. The upper 15 feet is most micaceous. The strata are almost horizontal. The quarry face is between 50 and 60 feet in height. Analyses of these varieties are given in the table of analyses on a later page. This quarry was reopened about 1916 by A. H. Burkholder, operating as the Quarryville Lime and Stone Co. It is equipped with motor-driven crushers and screens, and has six shaft kilns.

The Conestoga limestone extends in a narrow band east from Quarryville through the valley followed by the Pennsylvania Railroad between Quarryville and Coatesville in Chester County. At several places small quarries were opened many years ago for stone for agricultural lime. Three small quarries long abandoned are located about 2 miles from the Chester County line, all showing an admixture of coarsely crystalline marble and micaceous marble. About one mile south of Christiana and very close to the Chester County line, there is an old quarry that shows considerable fair grade limestone. An analysis is given in the table of analyses.

''Four quarries (3, p. 29) are operated in the Elbrook limestone along the Bareville-New Holland Ridge. The Levi F. Zook quarry is on the south side of the State highway at Bareville. It is about 150 feet long, 75 feet wide, and 75 feet deep. The rock is a thin-bedded, blue magnesian limestone with platy partings and lenses. Electric power is used for running the crusher, screens, air compressor, and hoist. Drilling is done with a jackhammer. The quarry is equipped with a New Holland crusher and the crushed stone is used on State highways, in local concrete constructions, and at the Bareville Concrete Works in making cement building blocks and conduits. South of the Levi Zook quarry is a small quarry operated by Clayton Groff.

The equipment consists of crusher and bins, and the product is crushed stone.

"By the school house on the State highway one mile west of New Holland is the Elmer Meyers quarry in the same formation the Elbrook. It is worked occasionally for foundation stones, and stone from this quarry was used in the Mennonite Church of New Holland. The rock is a well-bedded, cream-white marble occurring in two-foot beds and overlain by blue magnesian limestone. The quarry has no equipment and the slabs are broken out by hand when needed.

"The Aaron Good & Bros. quarry is half a mile south of New Holland. The rock exposed in the quarry dips 45° northwest. The quarry is 100 by 200 feet and 50 feet deep. The lower beds comprise 60 feet of sparkling, dark-blue, hackly dolomite which breaks readily, overlain by 30 feet of thicker bedded, light-blue dolomite, followed by 20 feet of banded, light-blue dolomite. The equipment includes an Ebersole crusher, screens and large bins, an air compressor and jackhammer drill. Electric power is used for all purposes. The coarser stone is used for road material and the pulverized rock for fertilizer.

"A quarry in blue mottled sparkling dolomite is operated on the place of James W. Brubaker, two miles south of New Holland. It is only a small quarry, worked intermittently. The rock is crushed for road material for use on the Earl Township roads."

J. C. Showalter is working a quarry at Blue Ball for crushed stone. The stone varies from gray to blue limestone with a little interbedded shale. The rock is hard but is quarried easily as it contains many veins and joints. The beds are folded but in general dip gently to the north. The quarry face, which is parallel to the strike, is about 300 feet long and 30 to 35 feet high. The clay overburden varies from 6 to 10 feet in depth. A few clay seams extend downward 25 to 30 feet. The output of the quarry is about 300 tons per day.

Brownstown area. Eli W. Shreiner operates a quarry for crushed stone on the north side of Conestoga Creek at Brownstown. The stone varies from a high magesian gray stone to a gray to dark blue compact dolomite rather high in silica. The rock is much shattered and contains numerous veins of calcite and quartz. In general the beds are nearly flat, dipping gently to the north but on the south side of the quarry they are intricately folded and also faulted. The quarry is about 360 feet long and the working face about 55 feet high. The overburden is shallow and there are no clay pockets. The production is about 60 tons per day but capacity is greater.

A cement company, called the Conestoga Portland Cement Co., was formed several years ago to make Portland cement from limestones one mile west of Brownstown. About 50 test holes averaging 100 feet in depth were bored and the results are reported to have been favorable. Only the stone of the best grade was to have been used. Shale to be mixed with the limestone was to be obtained about two-thirds of a mile to the northeast. On account of financial difficulties the plant was never erected.

"The following analyses (3, p. 22) from the report of Richard K. Meade, dated April 17, 1906, on the property of the Conestoga Portland Cement Company, show the variation in composition of the limestone in successive beds, as determined by samples taken every three feet in drill holes at the junction of Conestoga and Cocalico creeks.

The drilling was begun in Beekmantown limestone near the boundary with the underlying Conococheague limestone, into which the drilling probably extended."

Analyses of limestone from drill holes near Brownstown

	Hole No. 1				Hole No. 7			
	SiO_2	Fe_2O_3 Al_2O_3	$CaCO_3$	$MgCO_3$	SiO_2	Fe_2O_3 Al_2O_3	$CaCO_3$	$MgCO_3$
0– 3	19.58	3.82	73.73	1.18	11.68	2.92	81.40	3.00
3– 6	10.81	2.49	84.44	1.12	12.16	3.04	80.69	3.12
6– 9	7.78	1.94	88.26	1.02	29.88	7.52	57.50	3.10
9– 12	4.22	0.96	93.16	1.16	19.98	5.02	69.90	3.36
12– 15	1.28	0.42	97.32	0.98	39.82	9.96	44.20	3.02
15– 18	1.42	0.46	97.34	0.94	42.52	10.64	39.83	3.31
18– 21	1.38	0.43	97.34	1.10	45.00	11.26	36.12	3.62
21– 24	2.79	0.66	95.34	1.36	32.40	8.12	51.39	4.02
24– 27	2.41	0.62	95.70	1.48	32.64	8.36	52.11	3.81
27– 30	3.24	0.64	94.43	1.88	30.62	7.64	57.86	3.27
30– 33	3.33	0.75	94.07	1.73	13.56	3.28	76.24	3.98
33– 36	3.00	1.03	94.43	1.56	12.24	3.06	78.94	4.85
36– 39	3.90	1.14	93.34	1.62	14.83	3.72	75.83	4.62
39– 42	1.34	0.44	97.70	1.18	18.46	4.60	72.60	4.28
42– 45	1.30	0.30	97.70	1.15	32.18	12.96	49.41	4.12
45– 48	1.44	0.38	97.34	1.21	33.00	12.02	49.78	3.18
48– 51	1.32	0.42	97.65	1.12	34.22	13.68	46.72	3.02
51– 54	1.42	0.36	97.65	1.16	39.02	15.16	39.83	3.29
54– 57	1.36	0.48	97.65	1.18	30.62	12.44	51.93	2.50
57– 60	1.44	0.40	97.70	1.10	38.56	13.00	44.85	1.95
60– 63	0.62	0.18	98.43	1.01	36.66	13.06	45.82	2.16
63– 66	0.48	0.20	98.61	0.96	39.02	14.08	40.25	2.75
66– 69	1.10	0.32	97.88	1.02	39.98	14.56	37.20	3.60
69– 72	1.60	0.54	96.79	1.32	42.16	13.98	31.80	3.88
72– 75	4.38	0.66	92.62	2.72	47.20	13.82	26.06	4,98
75– 78	3.42	0.66	93.52	2.61	34.62	12.18	54.08	4.98
78– 81	4.83	1.66	91.42	2.81	30.68	12.36	50.67	4.82
81– 84	5.12	2.76	89.46	2.85	37.26	12.50	42.05	4.12
84– 87	5.62	3.02	88.74	2.84	37.62	12.22	42.05	4.16
87– 90	5.82	3.04	88.57	2.92	37.03	13.82	46.51	5.12
90– 93	5.94	3.18	88.39	2.96	37.16	13.54	46.69	4.10
93– 96	4.74	2.74	89.81	2.96	29.30	9.70	50.41	3.37
96– 99	--------	--------	--------	--------	39.04	14.00	34.32	4.18
96–100	4.70	2.75	89.99	3.04	--------	--------	--------	--------
99–102	--------	--------	--------	--------	38.98	14.44	35.22	4.00
102–105	--------	--------	--------	--------	--------	--------	--------	--------

Hole No. 9

Depth in feet	SiO_2	Fe_2O_3 Al_2O_3	$CaCO_3$	$MgCO_3$
0– 3	--------	--------	--------	--------
3– 6	--------	--------	--------	--------
6– 9	--------	--------	--------	--------
9– 12	--------	--------	--------	--------
12– 15	--------	--------	--------	--------
15– 18	--------	--------	--------	--------
18– 21	--------	--------	--------	--------
21– 24	--------	--------	--------	--------
24– 27	--------	--------	--------	--------
27– 30	--------	--------	--------	--------
33– 36	29.62	9.88	55.79	3.76
36– 39	15.24	5.08	74.63	3.96
39– 42	15.24	5.12	75.35	3.54
42– 45	9.84	3.26	82.70	3.62
45– 48	10.06	3.12	83.05	3.44
48– 51	12.22	4.00	80.47	3.12
51– 54	11.52	3.76	81.37	3.18
54– 57	4.54	1.48	92.03	2.16

Hole No. 9 (continued)

Depth in feet	SiO_2	Fe_2O_3 Al_2O_3	$CaCO_3$	$MgCO_3$
57– 60	4.50	1.36	91.85	2.54
60– 63	7.42	2.48	87.19	2.98
63– 66	2.75	3.28	83.60	2.86
66– 69	8.38	7.62	86.47	2.62
69– 72	9.64	3.22	82.34	3.06
72– 75	13.68	4.32	77.50	3.48
75– 78	11.64	3.88	79.29	3.12
78– 81	4.80	1.58	91.14	2.58
81– 84	6.36	2.12	88.62	2.62
84– 87	5.42	1.60	90.60	2.54
87– 90	2.78	1.02	94.18	2.18
90– 93	0.62	0.58	97.93	1.12
93– 96	0.31	0.21	99.01	0.54
96– 99	2.18	0.76	95.26	2.02
96–100	--------	--------	--------	--------
99–102	1.82	0.90	94.90	2.00
102–105	3.70	1.26	92.16	3.16

Hinkletown-Weaverland-Union Grove area. There is an idle quarry along the turnpike about halfway between Greenville and Hinkletown once operated by J. C. Showalter. It is in the Beekmantown limestone and exhibits interbedded high-lime and high-magnesian stone. Some poorly preserved gastropod fossils were noted. The quarry was first worked for lime and later for crushed stone.

About one mile north of Hinkletown a small quarry worked by Henry Martin shows crumpled Beekmantown limestone, thinly bedded and dark blue in color. It has been worked for road metal. Two abandoned small quarries lie to the east.

David Burkholder operates a quarry about three-fourths mile west of Martindale. Stone has been quarried here for fences and buildings but the product recently has been mainly crushed stone. The stone is a dense more or less magnesian limestone, gray to blue in color and very hard. The strata are fairly thick bedded, very regular, and dip to the southeast. The stripping varies from 0 to 3 feet. The quarry face is about 45 feet high. The daily production is about 400 tons of crushed stone.

"The quarry (3, p. 28) of William R. Good is just south of the Harrisburg-Downingtown road along a small tributary to Conestoga Creek near the east end of Hinkletown. The rock is hard blue dolomite crossed by a fault zone, in which the shattered limestone is stained red by infiltrations from the Triassic rocks. The equipment consists of a tram, cable, crusher, screens, elevator, and bins, used for the production of crushed stone. Just half a mile along the strike to the southwest is the Musselman quarry in the same kind of limestone, formerly operated by the New Holland Concrete Works. It is now idle and owned by W. R. Good."

Ferris Martin has a large crusher and produces from 400 to 500 tons of crushed stone daily from a quarry just east of Weaverland. The rock is interbedded, rather soft, high-calcium, gray limestone and dense, hard, blue limestone. The beds are of medium thickness. They have a general low dip to the north but in places are sharply folded. The quarry face is about 50 feet high at the highest point. There is very little clay overburden but a little rotten rock must be discarded.

About half a mile south of Terre Hill, C. S. Martin has within recent years operated a small quarry for crushed stone. The rock belongs to the Beekmantown formation and is interbedded limestone and dolomite, mainly the former. A thickness of about 20 feet has been worked in two benches. In 1930 one of the two old kilns was being repaired to make a trial burn.

At Union Grove the Beekmantown limestone with some interbedded dolomite was formerly quarried, first for lime and later for crushed stone.

Ephrata Area. About a mile southwest of Ephrata is the quarry of A. C. Kurtz and Sons. The quarry contains a variety of stone. The most common is a blue, tough dolomite. This overlies a light colored dolomite resembling porcelain with pinkish and greenish blotches and finely banded. The beds strike N.87°E., dip 24°NW. The clay overburden is light but a little rotten rock must be discarded. The product is entirely crushed stone. The finer sizes are hauled to the plant of Kurtz Bros. Concrete Product Co. less than one-fourth mile away to be made into concrete blocks of different kinds.

S. B. Keller operates a quarry about one-fourth mile southeast of Clay School. Most of the product is crushed for concrete work but a small amount of building stone is produced. The quarry is about 250 feet long, 100 feet wide, with a working face about 30 feet high. The rock is a good grade of dolomite. The beds are regular and strike

A. Weathered Vanport limestone, near Rasselas, Elk County.

B. Vanport limestone in stream bed north of New Bethlehem, Clarion County. Shows regular parallel jointing.

A. Loyalhanna limestone mine of Youghiogheny Crushed Stone Co., three miles southeast of Connellsville, Fayette County. View shows openings and supporting pillars.

B. Loyalhanna limestone quarry and mine of New Castle Lime and Stone Co., two miles east of Dunbar, Fayette County.

A. Typical outcrop of Upper Washington limestone and calcareous shales half a mile north of Holbrook, Greene County.

Photo by Allegheny County Bureau of Tests and Specifications.

B. Benwood limestone in Con-Oil quarry, one mile south of Clarksville, Greene County.

A. Dolomitic limestone quarry along the Susquehanna River, at Billmeyer, Lancaster County.

B. Crushed stone quarry in folded strata, Rheems, Lancaster County.

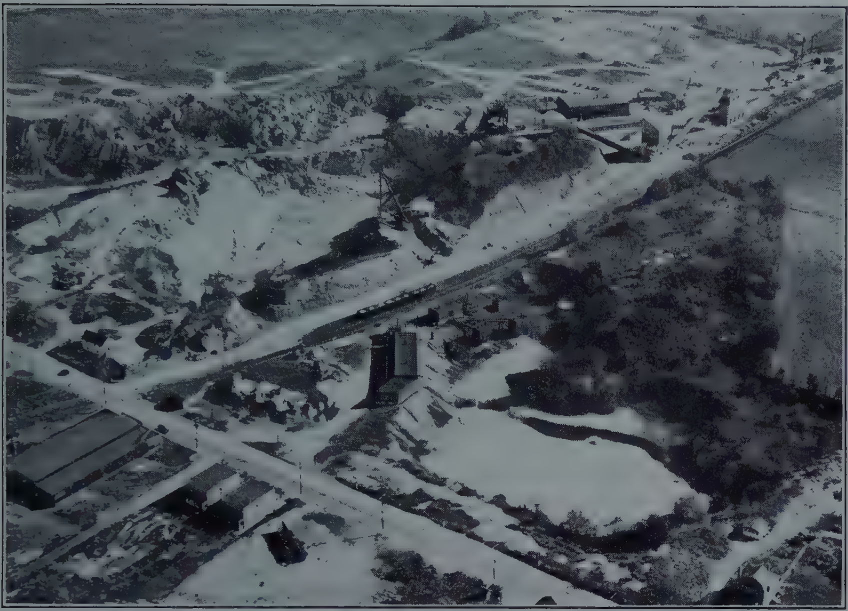
A. Vanport limestone quarry of Crucible Steel Co., Bessemer, Lawrence County.

B. Bessemer Limestone and Cement Co., Bessemer, Lawrence County.

C. Vanport limestone quarry of Bessemer Limestone and Cement Co.

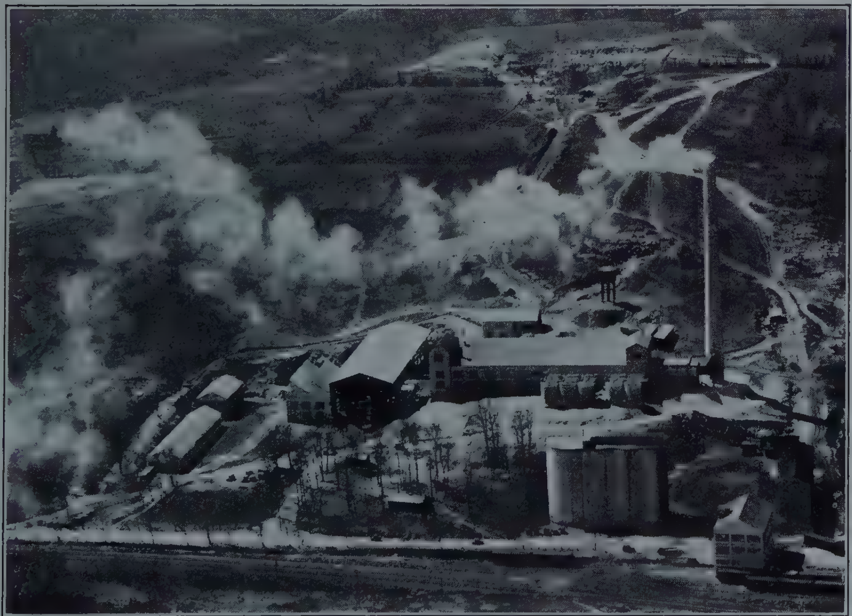
A. Quarry of Calcite Quarry Corporation, near Myerstown, Lebanon County.

B. Plant of Calcite Quarry Corporation, near Myerstown, Lebanon County.



Photograph by Wood Aerial Surveys, Inc., Philadelphia, Pa.

A. Airplane view of Bridgeport quarry of Bethlehem Mines Corporation, Bridgeport, Montgomery County.



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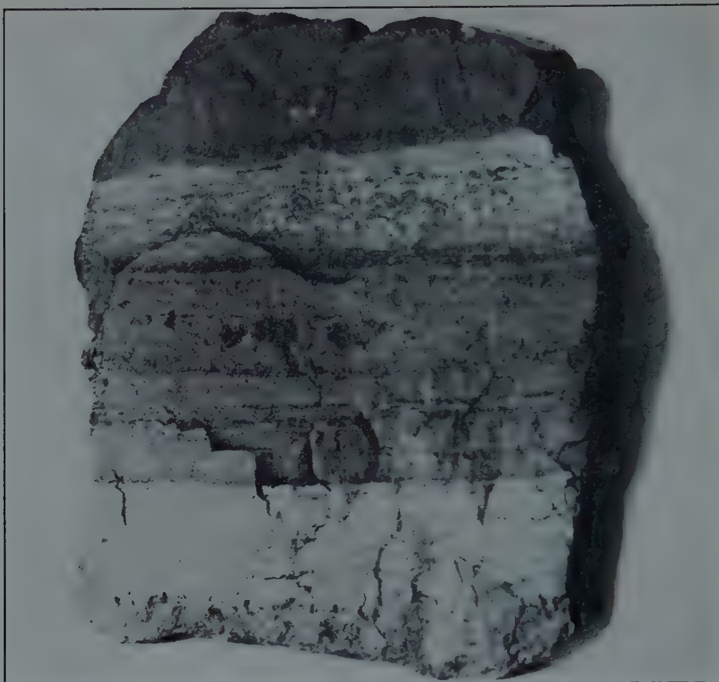
B. Plant of the Valley Forge Cement Company, West Conshohocken, Montgomery County.



A. Banding brought out by weathering indicating different amounts of magnesian carbonate. Lighter bands more dolomitic, upper one containing *Cryptozoon proliferum*. Bethlehem, Northampton County.

B. Alternation of massive magnesian limestones and shaly beds. Hellertown, Northampton County.

Cambrian (Conococheague or Allentown) limestone showing variable conditions of sedimentation.

N.75°E. with dip 28°SE. The clay overburden averages about 3 feet but in places is 8 to 10 feet with a few deeper pockets.

"West Cocalico Township (3, p. 27) operates two quarries for road material as needed. These quarries lie one mile south of Gockley and two miles south of Schoeneck respectively. The rock is thin blue limestone and blue dolomite."

Denver-Reamstown Area. Harry Millard once operated a large quarry about half a mile northeast of Denver in the Beekmantown limestone. The quarry was advanced into the hill about 400 feet and then abandoned as the cover of Triassic sandstone at that point was about 20 feet thick, overlying 80 feet of dolomite being extracted, and this overburden was increasing as the work was extended. The conditions were unfavorable for economic quarrying. The dolomite is gray in color. Some shaly limestone also is exposed. The product was crushed for road metal.

R. M. Hertzog has worked a quarry about one mile north of Reamstown for both lime and crushed stone. The quarry contains low-magnesian, high-magnesian, and shaly limestone. The rock is greatly shattered, with abundant calcite veins. The quarry is not promising in appearance.

TRIASSIC LIMESTONE

The Triassic in several sections of the State contains some limestone conglomerates. In one place in Adams County they have been quarried both for crushed stone and to burn for lime. In Maryland they were once quarried for decorative stone under the name of "Potomac marble." Prof. M. H. Bissell* in describing this type of stone in Lancaster County states that "a very extensive surface exposure, which, however, does not afford any vertical sections, occurs along the eastern margin of the Triassic belt east of the Susquehanna River in the vicinity of Bainbridge, especially along Conoy Creek."

CALCAREOUS MARL

Dr. H. Justin Roddy has found some interesting calcareous concretions in some of the streams of Lancaster County which are of great scientific interest. They possess little commercial value, although they have been dug in at least one place for putting on the soils. The following quotations are extracts from an article (8) in which Dr. Roddy describes the occurrences.

"In 1898, I discovered that concretionary formations occurred in Little Conestoga Creek, Lancaster County, Pa. At that time, however, I was engaged in other studies and gave the concretions only a passing notice. But in the late summer of 1914, my attention was directed to the subject again by the reading of Dr. Walcott's paper on "Pre-Cambrian Algonkian Algal Formations" which appeared July 22, 1914. This paper made me realize the importance of a careful investigation of these particular stream formations as to characteristics, distribution, origin, etc. I began at once a careful and extended search in the Little Conestoga as well as in other streams for concretionary structures of recent formation. My search was amply rewarded by finding them in great quantities, and distributed throughout nearly the entire length of the Little Conestoga. I found also that

*Personally communicated to the author.

they not only occur in the creek itself, but that quite large deposits of the concretions underlie the flood plain meadows along the creek banks. One of these in Kendig's Woods, two miles southwest of Millersville, Pa., is made up wholly of concretionary materials on the top of which forest trees of large size and considerable age are growing. This deposit covers nearly an acre to the depth of about 8 feet in the middle thinning out lenslike toward its edges. Another deposit along the same stream near Fruitville in Evan's Meadow, more extensive in area but of slighter depth, forms a substratum under a thick soil cover and has an average depth of about two feet. Deposited concretions occur under similar conditions in many other of the meadows along the stream as is shown by weathered concretions occurring in the soil and wash wherever wet-weather stream gullies have been torn through the soil cover."

"*Size and Shape.* The concretions both in the stream and in the deposits vary in size from peas to masses nearly a foot in diameter. The latter size is not very common in the stream but many large concretions occur in the deposits probably because the smaller ones after deposition in land forms have been carried away in solution by percolating waters leaving only the larger forms. In the flood deposits in Kendig's Woods thousands of the concretions when I found the deposit last summer measured nearly a foot in length and six inches or more in transverse diameter."

"*Composition and Hardness.* Though the composition varies slightly from place to place yet all are limy deposits concentric around a nucleus. The main constituents in the concentric layers are calcium carbonate, silica and organic matter of vegetable origin. Upon dissolving out the limy constituents with dilute hydrochloric acid, a mat is often left of vegetable materials composed of the matted stems or tissues and cells of low type plants such as mosses and algae.

"Few of the specimens tested had a hardness as great as that of common calcite, most of them being about two in the scale of hardness. The weathered concretions are generally less coherent than those now forming in the stream.

"The following table shows the main constituents of the concretions:

Constituents	A	B
Organic matter	10% to 15%	1% to 12%
H_2O	1%	1%
SiO_2	12%	12%
$CaCO_3$	60% to 75%	70% to 80%
Fe	1%	2%
Al	trace	trace
$MgCO_3$	trace to 1%	trace to 1%

A of growing specimens
B of specimens from flood plain deposit"

"*Structure.* Most specimens have as the nucleus a quartz or limestone pebble of the country rock. Near Millersville, where the stream flows for a mile or two parallel to an igneous dyke, the nuclei are diabase pebbles. But some specimens lack the stony nucleus, having instead the limy layers concentric around a dark spot which proves upon close examination to be carbonaceous matter resembling nearly structureless peat. Probably this was originally a piece of wood or other vegetable tissue that carbonized after the concretionary laminae

had accumulated around it. This supposition has been verified in a number of cases by finding concretions with organic matter as nuclei."

"*Where Found.* Upon recognizing the importance of a thorough study of the Algoid concretions, I began a systematic search in all parts of the Little Conestoga as well as in other streams of both Lancaster and York Counties, Pennsylvania. My search showed that these objects abound in all parts of the Little Conestoga nearly from source to mouth. But no other streams in this part of the State have so far yielded any specimens."

"Since writing the above I have been fortunate enough to find a new locality for concretions. Knowing that Donegal Township, Lancaster County, comprised a notably large area of Cambro-Ordovician limestones, I judged that its streams would be favorable to the growth of calcareous concretions through the agency of blue green algae. Search on April 25, in Donegal Creek, revealed these objects in greater abundance than in the Little Conestoga. One meadow of fully 12 acres bordering the stream about one mile northeast of Marietta was found to be underlain with a bed of concretions not less than a foot in average thickness throughout its entire extent. And this was under a soil cover of more than a foot in depth that had, apparently, resulted from the weathering and disintegration of the same objects. The great flood deposits of concretions in this and neighboring meadows were paralleled by large quantities in the stream itself, fully one-fifth of the stones in some places in the stream channel being of concretionary origin as shown by their shape, laminated structure, and composition."

Analyses of Lancaster County limestones

	1a	1b	2	3a	3b	3c	3d	4a
$CaCO_3$	94.87	94.99	78.70	83.50	83.76	85.10	91.88	90.99
$MgCO_3$	2.63	3.35	17.71	14.36	13.15	12.92	5.89	6.60
SiO_2	0.75	0.61	2.47	1.24	1.81	0.92	1.19	1.45
$Al_2O_3+Fe_2O_3$	1.09	0.54	0.99	0.81	0.95	0.75	0.51	0.61
S	0.015	0.015	---------	0.063	0.063	0.063	0.063	0.041
P	0.004	0.004	---------	0.008	0.008	0.008	0.008	0.006

	4b	5	6	7	8a	8b	8c	8d
$CaCO_3$	72.30	78.96	52.14	55.88	54.750	55.104	53.517	50.339
$MgCO_3$	19.85	---------	42.01	41.79	44.204	43.602	43.522	41.143
SiO_2	5.84	8.02	3.62	1.09	---------	---------	---------	---------
$Al_2O_3+Fe_2O_3$	1.93	1.63	1.92	0.98	.517	.304	.869	.731
S	0.041	---------	---------	0.006	.011	.023	.021	.030
P	0.006	---------	---------	0.006	.010	.016	.014	.029
Insoluble	---------	---------	---------	---------	.436	.847	1.926	7.699

1. Outcrops ⅔ mile west of Rheems on tract of J. A. Hipple. Average for phosphorus and sulphur.
2. Old Hipple quarries, ½ mile west of Rheems. Average analysis.
3. Quarry of J. A. Hipple, ½ mile SW. of Rheems. Average for phosphorus and sulphur.
4. H. K. Landis quarry, 1¼ miles south of Rheems. Average for phosphorus and sulphur.
5. Abandoned quarry on Brobaker farm, 1¼ miles north of Maytown.
6. Outcrop along left bank of a small stream, Rowenna P.O.
7. Hiestand quarry on east side of Donegal Creek, 1 mile from mouth. Average analysis.
8. Haldeman's quarries at Chickies. a. South quarry, best blue limestone. Fine grained and very hard, brittle; light bluish gray, with irregular fracture. b. North quarry, middle of quarry, best specimen. Rather coarse grained; hard and brittle; fracture irregular; light gray and brownish gray color. c. North quarry, middle of quarry, worst specimen. Rather coarse grained, hard and tough; fracture irreglar, dark bluish gray. d. North quarry, sandy layer at extreme north end of quarry. Specimen having the general appearance of a soft sand rock, is coarse grained and crumbling, brownish gray.

	9	10	11	12	13a	13b	14a	14b	14c
$CaCO_3$	54.51	54.63	54.93	55.01	55.07	72.11	72.21	68.88	71.82
$MgCO_3$	42.22	42.10	41.82	44.03	37.83	17.38	20.29	------	24.47
SiO_2	1.86	2.05	1.68	0.57	3.68	7.70	5.36	14.54	3.20
$Al_2O_3+Fe_2O_3$	1.85	1.82	1.09	0.67	1.41	2.72	1.84	5.18	1.04

9. Outcrop on left bank of Big Chickies Creek, Heinaman farm, 1¼ mile NE. of Chickies.
10. Outcrops on SE. side of Chickies Creek, ⅜ mile from mouth.
11. Quarry on left bank of Chickies Creek at junction of Big and Little Chickies creeks.
12. J. E. Baker quarry on right bank of Big Chickies Creek just above junction with Little Chickies Creek.
13. Quarry west wide of Little Chickies Creek, 2 miles S. of Mount Joy.
14. Outcrops and openings along left bank of Little Chickies Creek, 1½ to 1¾ miles south of Mount Joy.

	15	16	17	18	19	20	21
$CaCO_3$	54.96	55.03	90.00	78.16	63.54	54.84	53.54
$MgCO_3$	43.22	44.05	5.45	------	24.87	42.84	41.08
SiO_2	0.49	0.33	2.54	7.91	8.47	1.08	3.52
$Al_2O_3+Fe_2O_3$	0.65	0.68	0.81	5.82	2.81	1.24	1.85
S	0.009	0.009	------	------	------	------	------
P	0.008	0.008	------	------	------	------	------

15. Small quarry ¾ mile SW. of Newtown, midway between railroad and Big Chickies Creek.
16. Outcrop at road crossing of Big Chickies Creek, ½ mile SW. of Newtown.
17. Outcrop along left bank of Little Chickies Creek, near railroad, Mount Joy.
18. Quarry 2½ miles E. of Mount Joy on left bank of Big Chickies Creek.
19. Quarry ¼ mile S. of Centerville.
20. Outcrop on farm of Henry Musser, ¾ mile S. of Centerville.
21. Outcrop on farm of Chris. Musser, ½ mile S. of Centerville.

	22a	22b	22c	22d	22e	22f	22g	22h
$CaCO_3$	56.81	53.29	53.28	53.17	53.19	68.22	86.24	88.67
$MgCO_3$	40.23	43.77	45.28	44.04	43.73	29.08	12.71	10.53
SiO_2	------	------	------	------	------	------	------	------
$Al_2O_3+Fe_2O_3$	2.24	2.18	0.64	2.14	2.04	1.44	0.53	0.31
Insoluble	0.40	0.32	0.08	0.29	0.72	0.78	0.32	0.24
H_2O	0.32	0.44	0.72	0.36	0.32	0.48	0.20	0.25

22. Strickler limestone quarries half a mile east of the intersection of Strickler Run and the Lancaster and Columbia (Pennsylvania) R. R. Analyses by J. B. Britton.

	22i	22j	23a	23b	23c	23d	24
$CaCO_3$	83.46	90.89	74.46	91.97	56.03	69.13	93.91
$MgCO_3$	15.70	8.55	18.48	5.07	42.03	25.48	4.53
SiO_2	------	------	3.24	2.36	0.94	4.28	0.90
$Al_2O_3+Fe_2O_3$	0.40	0.20	1.10	0.82	1.23	1.25	0.56
S	------	------	0.018	0.018	0.018	------	0.047
P	------	------	0.006	0.006	0.006	------	0.009
Insoluble	0.12	0.12	------	------	------	------	------
H_2O	0.32	0.24	------	------	------	------	------

23. Stoner quarry at Pennsylvania R. R. crossing of Strickler Run SE. of Columbia. Average of three samples for phosphorus and sulphur.
24. Old Strickler quarry, ¾ mile SE. of Columbia.

	25a	25b	25c	26	27	28a	28b	28c
$CaCO_3$	92.53	90.81	86.89	94.23	53.93	52.28	54.23	74.42
$MgCO_3$	4.66	6.15	5.36	2.19	41.83	39.35	39.05	16.67
SiO_2	--------	--------	--------	1.69	2.54	--------	--------	--------
$Al_2O_3+Fe_2O_3$	0.84	1.18	2.40	0.59	1.65	4.51	2.88	1.51
S	--------	--------	--------	--------	0.010	--------	--------	--------
P	--------	--------	--------	--------	0.010	--------	--------	--------
Insoluble	1.61	1.38	4.03	--------	--------	3.38	3.42	7.12
H_2O	0.36	0.48	0.49	--------	--------	0.48	0.42	0.28

25. Limestones 300 yards NE. of the Strickler quarries. Analyses by J. B. Britton.
26. Quarry on Strickler Run, ⅝ mile west of Glenmanor.
27. Quarry at Glenmanor.
28. Limestones about ½ to 1½ miles south of Manheim along track of P. & R. R.R. and near County Bridge. Analyses by J. B. Britton.

	28d	28e	28f	28g	28h	28i	28j	28k
$CaCO_3$	86.50	93.34	89.17	88.77	90.64	93.24	87.75	57.43
$MgCO_3$	11.15	4.39	4.51	5.75	4.14	3.56	5.16	24.73
SiO_2	--------	--------	--------	--------	--------	--------	--------	--------
$Al_2O_3+Fe_2O_3$	0.54	0.29	0.44	0.64	0.58	0.40	0.44	3.36
S	--------	--------	--------	--------	--------	--------	--------	--------
P	--------	--------	--------	--------	--------	--------	--------	--------
Insoluble	1.45	1.62	5.60	4.52	4.08	2.28	6.25	13.96
H_2O	0.36	0.36	0.28	0.32	0.56	0.52	0.20	0.52

	29	30a	30b	30c	31	32	33	34
$CaCO_3$	55.01	82.50	54.50	61.64	51.03	97.25	67.08	91.49
$MgCO_3$	42.85	15.88	42.94	34.36	37.62	1.49	30.30	7.23
SiO_2	1.40	1.08	1.49	2.54	7.81	0.61	1.53	0.85
$Al_2O_3+Fe_2O_3$	0.76	0.58	0.85	1.51	3.74	0.53	1.09	0.46
S	0.037	--------	--------	--------	--------	--------	--------	--------
P	0.007	--------	--------	--------	--------	--------	--------	--------

	35a	35b	35c	36
$CaCO_3$	52.06	55.42	55.35	82.14
$MgCO_3$	--------	44.26	43.71	9.03
SiO_2	5.08	0.28	0.49	7.04
$Al_2O_3+Fe_2O_3$	0.71	0.42	0.45	4.72
S	0.006	0.006	0.006	--------
P	0.014	0.014	0.014	--------

29. Large quarry between Lititz and Fruitville turnpikes, 1 mile N. of Lancaster. Average analysis.
30. H. H. Landis quarry, ½ mile SE. of Landis Valley. Average for phosphorus and sulphur.
31. Outcrop, south of Ephrata turnpike, 1¼ miles E. of Landis Valley.
32. Outcrop on Weidler farm near right bank of Cocalico Creek, 1 mile E. of Oregon.
33. Outcrop on Minnich farm near abandoned railroad cut. 1 mile N. of Brownstown.
34. Quarry near left bank of Conestoga Creek 1 mile NW. of Farmersville.
35. Bellemont quarries, east of Bellemont. Average for phosphorus and sulphur.
36. Old quarry 1½ miles south of Christiana.

	37	38	39
SiO_2	27.94	7.56	24.48
$Al_2O_3+Fe_2O_3$	13.44	3.56	4.36
CaO	28.32	48.46	38.12
MgO	3.16	.94	.77
Loss	25.03	37.68	30.61
Total	97.89	98.20	98.34
$CaCO_3$	50.58	81.18	68.08

37. Orchard quarry, Quarryville, micaceous limestone.
38. Orchard quarry, Quarryville, gray limestone.
39. Orchard quarry, Quarryville, white limestone. Analyses 1-5, 7, 10-21, 23, 24, 26, 27, 29-35 by Bethlehem Steel Co.

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LAWRENCE COUNTY

Lawrence County is one of the most important limestone producing counties of Pennsylvania. This position it holds because of the extensive development of the Vanport limestone and the readiness with which it can be quarried and mined. The Portland cement and fluxing stone industries take most of the stone. Other limestone beds are present but they are not now of any significance and in the past have only been worked in a small way in a few localities.

General geologic section of Lawrence County

Conemaugh group
- Buffalo sandstone
- *Brush Creek limestone*
- Brush Creek coal
- Mahoning sandstone

Allegheny group
- Upper Freeport coal
- *Upper Freeport limestone*
- Upper Freeport fire clay
- Upper Freeport (Butler) sandstone
- Lower Freeport coal
- *Lower Freeport (Butler) limestone*
- Lower Freeport sandstone
- Upper Kittanning (Darlington) coal
- Middle Kittanning coal
- Lower Kittanning coal
- Kittanning fire clay
- Kittanning sandstone and shale
- *Vanport (Ferriferous) limestone*
- Scrubgrass coal
- Clarion coal
- Fire clay
- Brookville coal

Pottsville series
- Homewood (Piedmont or Tionesta) sandstone
- Tionesta coal
- Tionesta iron shales
- *Upper Mercer (Upper Wurtemburg) limestone*
- Upper Mercer coal
- Upper Mercer iron shales
- *Lower Mercer (Lower Wurtemburg) limestone*
- Lower Mercer coal
- Lower Mercer iron shales
- Upper Connoquenessing sandstone
- Quakertown coal
- Quakertown iron shales
- Lower Connoquenessing sandstone
- Sharon iron shales
- Sharon coal
- Sharon conglomerate

Pocono series
- Burgoon group
  - Shenango shale

In the table above, only the named beds are mentioned. These include all of the coals and limestones, but only a portion of the shales and sandstones.

The strata of the county are regular and lie nearly flat. There is a general slight dip to the south and locally there are other slight irregularities but seldom if ever are the strata of economic importance sufficiently irregular as to interfere with quarrying and mining them.

MERCER LIMESTONES

Lower Mercer limestone. In Lawrence County the Lower Mercer limestone is one of the most persistent members of the Pottsville series. It lies from 110 to 135 feet below the Vanport limestone. Although of varying thickness it is more generally from 2 to 2½ feet thick. It is dark blue, highly fossiliferous, and breaks with a conchoidal fracture. Carbonate iron ore is developed in association with the limestone and in some cases both iron ore and flux from this horizon were obtained during the time when the carbonate ores of western Pennsylvania were being worked.

This limestone has practically no economic significance mainly because of its slight thickness, but more because of its proximity to the important deposits of the Vanport.

Upper Mercer limestone. The Upper Mercer limestone is likewise scarcely worthy of mention in a description of the limestone resources of Lawrence County. It is extensively developed in the valleys of Beaver, Mahoning, and Shenango rivers and Slippery Rock Creek. It varies considerably in thickness but in most places is from 2 to 4 feet thick. It is dark gray to dark bluish in color, hard, compact, and fairly fossiliferous. Iron concretions are common.

Half a mile south of Mount Jackson the Upper Mercer limestone in the bottom of Hickory Run is 2 feet thick and rather impure. The stream cascades over it at this point. Another good exposure of the limestone is to be seen just east of Wurtemburg along Slippery Rock Creek where it measures 12 to 14 inches. Beneath it occurs 12 to 18 inches of coal. The limestone here is a lens.

Fig. 21. Limestone areas in Lawrence County.

1. Lehigh Portland Cement Co. 2. Carbon Limestone Co. 3. Lake Erie Limestone Co. 4. George W. Johnson Co. 5. Union Limestone Co. 6. Pittsburgh Crucible Steel Co. 7. Bessemer Limestone & Cement Co. 8. Medusa Portland Cement Co. 9. Consolidated Stone and Mining Co. 10. Duck Run quarry. 11. Rose Point quarry. 12. Interstate Limestone Co. 13. Lawrence Limestone Co.

VANPORT LIMESTONE

The Vanport limestone in recent years has been more extensively worked in Lawrence County than in any of the other counties of western Pennsylvania. This is due to its thickness, uniformity, and the ease with which it can be quarried. Extensive areas in the vicinity of New Castle, Hillside, and Bessemer contain the limestone either forming the caps of the hills or covered with so little overlying soil and shale that the limestone can be readily obtained by

stripping. The limestone has been removed over a number of square miles and with improvements in stripping machinery it will be economical to strip the overburden from much additional territory. In the southern part of the county where the Vanport lies deeper, underground mining has been carried on, especially at Wampum.

In 1919 the late Professor F. B. Peck made a detailed study of the Vanport limestone of Lawrence County for the State Highway Department and submitted a report which was never printed. This report is in hand and has been freely used in this description but modified and amplified in many places as the result of the writer's less complete personal investigations in 1921 and 1929. However, to one familiar with the district, it may be apparent that some of the notes of particular areas may be somewhat out-of-date.

In Lawrence County the Vanport limestone is remarkably persistent and uniform in both thickness and character. In thickness it ranges from 14 to 23 feet, with an average in the majority of localities where it was examined (at outcrops or in quarries) of 18 feet. In most places several distinct benches or subdivisions in the formation can easily be distinguished, owing to somewhat pronounced changes in the lithological and chemical character of the rock. Usually the upper bench, 5 to 8 or even 12 feet thick, consists of gray, highly fossiliferous limestone, in which the bedding planes are rather widely separated and regular in character, giving this part of the formation a thick or heavy bedded appearance. This upper bench breaks with a conchoidal fracture into angular fragments, rudely equidimensional.

Below this upper bench usually occurs 2 feet of a more or less slaty variety of limestone which has a tendency to break in long, flat pieces. This slaty character is exaggerated on weathering, for where the rock has been long exposed, the slaty character is clearly visible. Usually, however, where the rock is freshly broken, its slaty character is not particularly noticeable and would not detract materially from its good road building qualities.

Below this somewhat slaty bed usually comes 2 to 5 feet of purer limestone, the purest in the formation. It is sometimes called the "Bull layer or bed" and sometimes goes by the name of the "20-inch seam or bed." It breaks into equidimensional fragments and has an irregular or conchoidal fracture.

Below this bench of purer limestone lies 3 to 5 feet of dark blue limestone, having a rather thin and very irregular bedding which gives the limestone a decidedly warty or knotty appearance. It is usually very hard and splintery, and breaks into irregular fragments. Chemically it is somewhat impure. The bottom layer, a foot or less in thickness, is often flinty in character and seems to be decidely impure. It is sometimes referred to as "bottom rock."

These various horizons or benches are not always distinguishable in different quarries. Occasionally, however, the upper gray limestone with its thick, regular bedding comprises nearly two-thirds of the entire thickness of the Vanport and can be quickly and easily distinguished from the blue, knotty limestone below with its thin, irregular bedding. The upper gray portion is the rock best suited for flux; the lower bench of blue limestone is less suited to that purpose and is sometimes left in the floor to be quarried later for ballast or concrete. Both the gray and the blue, as well as the slaty beds, are

suitable for cement making, and occasionally the blue is sold as flux for open hearth furnaces.

It is not possible nor would it be desirable to include all of the available information concerning the Vanport quarries and outcrops in Lawrence County and for that reason the descriptions will deal with certain areas and individual operations. The accompanying map shows the distribution of the outcrops.

QUARRIES IN OPERATION

Lehigh Portland Cement Company's Plant, New Castle. The quarries and plant of the Lehigh Portland Cement Company are located partly within, but mainly adjoining, the eastern limit of the city of New Castle. Three mills were at one time operated here but in 1929 two were being dismantled. Three large quarries have also been worked here but one has been abandoned as the overburden of shale and sandstone had increased to a thickness of 40 feet which was too great for profitable work. The overburden in the other quarries averages between 15 and 25 feet. The Vanport averages 14 feet in thickness. The shale overlying the limestone and also at times some of the sandstone is used to obtain the proper cement mixture. When visited in 1929 a small amount of sand was being used with the limestone and shale but this was all surficial glacial sand which occurs in some places. In general it is necessary to use about 83.5 per cent of limestone to 16.5 per cent shale and sand to obtain the proper composition. Ordinarily it means 3 carloads of shale, a dipper of sand, and 10 carloads of limestone. Naturally, the proportions vary with the composition of the limestone, which ranges from 86 to 94 per cent in $CaCO_3$.

The Vanport is separated into three layers, the upper 4 to 5 feet thick, the middle 6 feet, and the lower 4 to 5 feet. There is also some shaly material beneath, which is left in the quarry. Analyses of these three layers are given below, each layer divided into 5 samples. They show the middle layer to be the best stone and the bottom one the poorest.

Analyses of Vanport Limestone at New Castle

Top	1	2	3	4	5
CaO	52.14	52.73	51.29	53.68	54.42
Al_2O_3–Fe_2O_3	2.40	2.50	2.66	2.46	1.60
SiO_2	2.50	2.36	3.60	1.00	1.00
V. M.	40.68	41.74	40.36	41.84	42.50
$CaCO_3$	93.11	94.16	91.59	95.89	97.21
$MgCO_3$	1.62				
Middle	**1**	**2**	**3**	**4**	**5**
CaO	53.69	53.05	53.58	53.14	52.99
Al_2O_3–Fe_2O_3	2.18	2.94	1.50	2.18	2.58
SiO_2	1.70	2.74	2.00	2.32	2.46
V. M.	41.46	40.70	41.40	41.00	41.56
$CaCO_3$	95.88	94.73	95.69	93.65	94.93
$MgCO_3$		1.43			1.51
Bottom	**1**	**2**	**3**	**4**	**5**
CaO	48.67	49.79	49.78	46.77	46.22
Al_2O_3–Fe_2O_3	5.00	3.60	4.58	6.50	6.50
SiO_2	5.60	5.30	5.36	8.20	8.58
V. M.	38.46	38.58	38.86	36.14	36.30
$CaCO_3$	86.92	88.91	88.92	83.54	82.57
$MgCO_3$			1.69		

The following analyses of the shale indicate its remarkably uniform composition.

Analyses of shale of Lehigh Portland Cement Company, New Castle

CaO	1.49	1.23	1.04	1.65	1.10	1.34
MgO	2.27	2.41	1.97	1.86	2.33	2.38
Al_2O_3	30.58	28.78	28.22	26.58	29.10	28.34
Fe_2O_3	------	5.37	6.57	7.01	7.26	7.26
SiO_2	56.78	55.12	59.04	60.96	54.96	55.80
V. M.	8.80	8.00	7.56	6.98	8.00	7.40

Hillsville Area. Four companies are operating large open cut quarries in the Vanport limestone in the region immediately south of Hillsville. The quarries of this region are impressive because of their great areal extent and the large amount of overburden being removed. The quarries extend from the Ohio line eastward to a short distance beyond Miller School, a distance of more than 3 miles. The most westerly is The Carbon Limestone Company, with offices in Youngstown, Ohio. Their company also works across the line in Ohio to a limited extent. The Lake Erie Limestone Company, affiliated with the New Castle Lime and Stone Company, has its quarry to the east of the Carbon quarry and separated from it by a high ridge of tailings. East of the Lake Erie quarry is that of the Geo. W. Johnson Company, affiliated with the Pittsburgh Limestone Company, and still further east is the Union Limestone Company of Youngstown, Ohio. All of them work in the same manner, which consists of stripping the shale and clay and then removing the limestone. The stripped material is dumped in the place from which the stone has been removed. As the quarry advances great banks of earth are left behind.

Throughout the Hillsville region the Vanport has a fairly uniform thickness of 22 feet and varies little lithologically throughout the four quarries. The best section obtainable at the time of our visit was in the Lake Erie quarry and this may be regarded as typical. Each quarry will be described briefly beginning at the Ohio line and progressing eastward.

The Carbon Limestone Company is operating a face about 1½ miles long and has crossed into Ohio for a short distance. The layer of "buhrstone" iron ore which so generally lies above the Vanport is here about 1 foot thick. It is a deep reddish-brown, ferruginous limestone, in places slightly oolitic near the base. Almost everywhere a thin layer of chert or chalcedony about an inch in thickness separates the iron ore layer from the unchanged Vanport limestone. The company has two large Marion shovels with a capacity each of 9 cubic yards and 90-foot booms.

The average overburden stripped is 38 feet. A section of the material stripped and the limestone is about as follows:

	Ft.	*in.*
Surface soil, variable in thickness		
Coal		8 to 9
Shale	4	2
Lower Kittanning coal	2	6
Fire clay	3	
Shale	30	
Vanport limestone	22	

The company has a capacity of over 1,000,000 tons annually divided into about 750,000 tons of fluxing stone, most of which is shipped into the Pittsburgh district, about 400,000 tons of crushed stone aggregates and 60,000 tons of pulverized stone ground to 100-mesh size for agricultural uses. An average analysis of the 1926 production is as follows:

Analysis of Vanport limestone at Carbon Limestone Co. quarry

CaO	52.80
MgO	.62
Al_2O_3, Fe_2O_3	2.15
SiO_2	2.05
P_2O_5	.031
S	.072
$CaCO_3$	94.29
$MgCO_3$	1.30

The Lake Erie Limestone Company operating to the east of the Carbon Company has an overburden averaging 27 to 30 feet and consisting chiefly of unconsolidated glacial gravels. Near the western boundary there is some shale overburden. The quarry face which is about half a mile long is about three-fourths mile from the crushing plant. The limestone is generally about 21 feet or a trifle more in thickness of which the upper 17 feet consists of gray stone and the lower 4 feet of blue stone.

A detailed section is as follows:

	Ft.	in.
Gray, massive, light chocolate or dove-colored stone when weathered, slightly pinkish when fresh. Breaks with a gnarly fracture. This bed rarely shows any laminations	3	4
Gray stone similar to above but with some laminations along which it breaks	3	4
Similar gray stone but with three breaks at 16, 25 and 32 inches from the top	3	3
Closely laminated gray limestone locally known as "muck" layer		11
Gray massive limestone with imperfect lamination at 11, 20 and 40 inches from the top	6	8
Blue massive limestone	4	0

The uppermost gray stone layer and the blue stone at the base contain more phosphorus and iron than the other layers and yield a non-Bessemer fluxing stone. The other is suitable for Bessemer use.

The company mainly produces fluxing stone amounting to about 750,000 tons annually, shipped to Youngstown, Sharpsville, and other points. It produces about 250,000 tons of crushed stone aggregates; some is shipped to cement plants and 30,000 tons or more is pulverized for agricultural limestone or for mine dusting. For agricultural purposes the stone is crushed sufficiently for 65 per cent to pass through a 100-mesh screen and for mine dusting for 70 per cent to pass through a 200-mesh screen.

Analyses of Lake Erie Limestone Company's stone

	1	2	3	4	5
SiO_2	2.60	1.89	1.78	1.62	1.83
Al_2O_3	1.39	.40	.67	.68	.57
Fe_2O_3	1.90	.50	.71	.57	.56
TiO_2	......	tr	tr	tr	tr
$CaCO_3$	......	96.68	96.05	96.49	96.86
$MgCO_3$		low—not determined			
SO_3			trace		
P_2O_5	......	tr	.034	tr	tr
Organic	......	.40	......	.37	.06
CaO	52.00				
MgO	0.29				
P	0.082				

	6	7	8	9	10
SiO	3.13	1.95	3.59	0.96	6.62
Al_2O_3	1.66	1.43	1.77	.17	4.24
Fe_2O_3	.86	.84	.93	.86	.71
TiO_2	tr	.10	.10	.10	.10
$CaCO_3$	93.55	94.89	93.00	97.22	88.42
$MgCO_3$		low not determined			
SO_3			trace		
P_2O_5	tr	.030	.030	tr	tr
Organic	.47	......	.31	.44	......

1. Composite analysis of 10 samples.

2 to 10. Samples from top to bottom of section. Nos. 2 to 7 inclusive from graystone, 8 to 10 blue stone.

Geo. W. Johnson Limestone Co. The largest operation in the Hillsville area is that of the Geo. W. Johnson Limestone Co. The working face is about 2¼ miles long. Near the center the overburden increases to a depth of 55 feet and underground mining is there being carried on. The overburden in part of the property is entirely loose glacial debris, clay, and sand, in which there are occasional large boulders of granite, gneiss, and sandstone. In a few places the glacier cut deeply into the limestone, removing most of the gray stone. Where glacial erosion was less severe the limestone is overlain by greenish shales.

Section of the Vanport limestone at Geo. W. Johnson Co. Quarry

	Ft.	*in.*
Massive gray limestone	8	0
Gray massive limestone, showing some laminations	3	9
Massive gray limestone showing numerous thin laminations on weathering	4	10
Massive blue limestone	1	0
Gnarly blue limestone		8
Massive blue stone	3	2

The gray limestone is suitable for Bessemer use and the blue is called non-Bessemer fluxing stone. The bulk of the product is used for flux but in addition a large amount of crushed stone and screenings is also marketed. The total output is given as 1,400,000 tons.

Union Limestone Co. The most easterly operation in the Hillsville region is that of the Union Limestone Co. with offices in Youngstown,

Summary of drill samples representing cross section of limestone deposit in Geo. W. Johnson Co.'s quarry at different locations

Location No.	Color	Thickness inches	Ignition loss	SiO_2	Al_2O_3 $+Fe_2O_3$	CaO	MgO	P	S
		6 in	40.60	5.18	4.28	49.00	.60	.146	.092
		126½	42.66	1.84	1.40	53.20	.49	.034	.069
1	Gray	71½	40.46	4.86	3.28	50.60	.53	.027	.091
		Tot. 17 ft	Av. 41.83	Av. 3.01	Av. 2.14	Av. 52.17	Av. .51	Av. .035	Av. .078
	Blue	4 ft	42.03	2.22	1.86	53.00	.54	.050	.093
		Tot. 21 ft							
		6 in	41.20	1.48	10.40	45.90	1.02	.084	.065
		127½	42.02	2.48	1.84	52.50	.43	.031	.049
2	Gray	75½	40.59	5.08	3.30	50.20	.54	.036	.087
		Tot. 17′ 5″	Av. 41.18	Av. 3.39	Av. 2.61	Av. 51.48	Av. .49	Av. .034	Av. .063
(High P.)	Blue	4 ft	42.38	2.25	1.96	52.60	.54	.048	.111
		Tot. 21′ 5″							
		6 in	39.79	3.74	10.78	44.60	.86	.144	.045
		114	42.39	1.79	1.40	53.40	.48	.042	.027
		84	40.52	4.61	3.00	50.30	.52	.036	.068
3	Gray	Tot. 17 ft	Av. 41.54	Av. 3.01	Av. 2.33	Av. 51.85	Av. .51	Av. .042	Av. .045
	Blue	4 ft	41.88	2.47	2.14	52.70	.58	.066	.061
		Tot. 21 ft				General Summary			
Combination		6 in	40.53	3.47	8.45	46.50	.83	.125	.067
		123	42.36	2.04	1.55	53.03	.47	.036	.048
		77	40.52	4.85	3.19	50.37	.53	.033	.082
1, 2 and 3	Gray	Tot. 17′ 2″	Av. 41.52	Av. 3.14	Av. 2.36	Av. 51.83	Av. .50	Av. .037	Av. .062
	Blue	Av. 4 f'	Av. 42.10	Av. 2.31	Av. 1.39	Av. 52.77	Av. .55	Av. .055	Av. .088
		Tot. 21′ 2							

Ohio. The Vanport here is similar to that in the other quarries just described. A section at one point is as follows:

Section of Vanport limestone at Union limestone quarry

	Ft.	in.
Gray limestone with upper 4 inches highly impregnated with iron	3	10
Gray massive limestone with numerous crinoid stems	2	9
Mud seam that is fairly continuous		2
Massive gray limestone, sparingly fossiliferous	3	9
Massive gray limestone that shows laminations where weathered and that shatters when shot	5	2
Blue limestone separated into beds from 4 to 6 inches thick	4	1

The section given measures 19 feet 9 inches thick, which is somewhat less than the average, which is probably 21 to 22 feet. The overburden averages about 27 feet but in places runs as high as 40 feet. It is chiefly unconsolidated glacial sand, clay, and boulders. The bulk of the stone, about two-thirds, is used for flux, going mainly to iron furnaces at Sharpsville. This is the stone that measures from 1½ to 6 inches in size. The balance is commercial crushed stone. The annual production is given as 750,000 tons.

Pittsburgh Crucible Steel Co. quarry at Bessemer. At Bessemer a rather large quarry is being worked by the Pittsburgh Crucible Steel Co. The quarry face which extends in an almost east-west direction is about half a mile long. The overburden, which averages 27 feet in thickness, is mainly shale but with some unconsolidated glacial material. At the eastern end it runs up to 40 feet but no further stripping is planned for that part of the quarry. A section taken at a narrow cut between the eastern and western portions of the quarry is as follows:

Section of Vanport limestone at Pittsburgh Crucible Steel Co. quarry

	Ft.	in.
Gray limestone containing some iron carbonate		11
Massive gray limestone which breaks into 3 beds when shot. Shows stylolitic structure	4	1
Massive gray limestone more crystalline than above	3	0
Massive gray limestone	4	7
Gray limestone, somewhat gnarly with numerous laminations in upper 2 feet	5	0
Blue to almost black limestone, upper 11 inches showing 4 distinct laminae	5	4

The band of ferruginous limestone that so commonly overlies the Vanport limestone is distinctly seen in several places and the thin band of cherty material less commonly developed was also noted in a few places.

The stone is loaded by hand. The product is mainly used for flux.

Bessemer Limestone and Cement Co., Bessemer. The Bessemer Limestone and Cement Co. is engaged in the manufacture of Portland cement and also in the production of fluxing stone and commercial crushed stone. At first only the fine material separated from the fluxing stone was used for cement but at present the bulk of the limestone

quarried is used for this purpose. The overburden is heavy, running up to 70 feet in one place. This is mainly shale but there is a thin bed of coal. Some of the stripped shale is sold to a near-by brick plant for manufacture of brick and part is used by the company to mix with the limestone for the cement mixture but most of the material overlying the limestone is wasted. The shale used in the cement plant is light greenish gray in color. The band of iron ore on top of the limestone is unusually thick in some parts of the quarry.

Section of Vanport limestone at Bessemer Limestone and Cement Co. quarry

	Ft.	in.
Iron ore and ferruginous limestone, maximum	4	0
Gray massive limestone	6	0
Shaly limestone		6
Gray massive limestone	5	0
Shaly limestone	1	0
Blue gnarly limestone, fairly thin bedded	11	0

Where the iron ore is thicker than one foot, the next underlying layer of limestone is correspondingly thinner. Where thickest the upper portion is thoroughly oxidized and is bright red, yellow, or yellowish-brown.

A prominent downward fold (syncline) about 100 feet in width is present at one point and here the base of the limestone is about 8 feet below the general level of the quarry floor. It is seldom that one encounters folds of this kind in the Vanport limestone of Lawrence County.

The capacity of the cement plant is given as 5000 barrels per day. The wet process is used.

Average analyses of the Vanport limestone used on four days by the cement plant

(1929)	July 25	July 26	July 27	July 29
CaO	47.98	50.40	49.40	48.40
MgO	Not determined usually but fairly uniformly .9 per cent			
Al_2O_3	3.48	1.65	2.23	3.24
Fe_2O_3	2.02	1.43	1.67	1.90
SiO_2	7.76	5.50	6.86	7.14

Medusa Portland Cement Co. (formerly Crescent Portland Cement Co.), Wampum. One of the earliest plants for the manufacture of Portland cement was at Wampum, where the Medusa Portland Cement Co. is now operating. The early history of this operation is described by Robert W. Lesley in "History of the Portland Cement Industry in the United States" as follows:

"Another important early portland cement plant was that erected about 1875 by John K. Shinn, at Wampum, Pennsylvania. Some have claimed that it was in this plant the manufacture of American portland cement first took place.

"Before the manufacture of portland cement began at Wampum, the Wampum Mining and Manufacturing Company was in operation

there. John K. Shinn was secretary and treasurer of the company, which was succeeded by the National Cement Company and later by the Crescent Portland Cement Company. After years of experiment, Mr. Shinn began, in 1874, to manufacture portland cement, but without entire success. Sometimes a good product would be produced and at other times failure would result. He advertised for an experienced cement maker and finally employed William Pucall, of Cincinnati. Mr. Pucall worked earnestly, putting in days and nights at a stretch. He erected a kiln, or furnace, with which he succeeded in obtaining a portland cement of uniform quality. It was exhibited at the Centennial Exhibition held in Philadelphia in 1876, and the firm was awarded a gold medal by the United States Centennial Commission. Associated with Mr. Shinn at the time were W. P. Shinn, president of the company, and Joseph Shinn, superintendent.

"In the beginning many difficulties were encountered and the methods employed were very primitive. For example, in the reduction of clinker a groove conforming to the outline of a box was cut in a flat rock and into this was fitted the box in which the burnt clinker was placed and pounded, or pulverized. This was done by means of a heavy car axle with the end stove up, the axle suspended from a spring pole such as is used in drilling small wells. This crude process preceded the use of modern mills. Having no apparatus for crushing or grinding the limestone, a carload of material would be sent to Leetonia, Ohio, where it would be crushed and sent back to Newport, near Wampum, and taken to a sawmill in which the owner had rigged up a set of chopping buhrs. The limestone was run through these buhrs and ground as fine as possible, and then brought down to Wampum.

"Under Mr. Shinn's plans, Mr. Pucall built a square kiln of fire brick, six or seven feet outside measurement and about eight feet high, the walls about a foot thick. The chimney was at one side of the top and a firebox was placed at the bottom of the kiln. The lime was mixed in certain proportions with a blue clay found nearby. The clay and limestone, finely ground, were mixed together wet. This mixture was shaped in fire brick molds, the material being taken to a brick yard for that purpose, where the bricks were dried on a hot floor. They were then brought back and placed in the kiln with alternate layers of coke, and burned. After burning, the brick were shipped to Cunningham's foundry in Newcastle, Pennsylvania, where they were ground on a set of buhr stones.

"On November 1, 1878, Mr. Shinn, whose residence was given as Newcastle, Lawrence County, Pennsylvania, took out a patent on an improved method of burning lime and cement by means of a mechanical device designed to inject a forced draft into the lower part of the kiln. In the first or burning stage, combustion was promoted thereby and later cooling of the kiln contents expedited."

The stone was for a long time obtained from an open-cut quarry on the side of the hill where it outcrops but when the overburden became too heavy for profitable quarrying the ledge was followed underground. All of the stone now used is obtained by mining. The experience of the company is that open cut quarrying is cheaper until the necessary stripping exceeds about 25 feet, beyond which mining is more economical.

Section of the Vanport at the Medusa Portland Cement Co. quarry

	Ft.	*in.*
Gray limestone. In entries all is left as roof but in rooms half only is left	8	0
Hard gray limestone showing bedding planes and containing numerous fossil crinoid stems. Is known as "bull layer"	1	3
Gray thin-bedded argillaceous limestone or thin-bedded limestone with numerous thin shale layers. When fresh it breaks into splinters and on weathering breaks into very thin layers. Is known as "rotten layer"	1	3
Blue limestone varying from dark chocolate to dark blue when fresh and weathering to a dove color. Few bedding planes are observable except where weathered. Is semi-crystalline and sparingly fossiliferous. Upper and lower portions vary somewhat in chemical composition	7-9	0

The iron ore band so commonly developed on top of the Vanport seems to be missing, but on the east side of Beaver River it is said to have been unusually thick and was extensively mined. In one place the entire limestone bed is reported to have been replaced by iron carbonate, later changed in part to red and yellow iron oxides.

The limestone is mined in 60-foot centers, leaving 30-foot pillars. In places the width of the entry is somewhat greater but near the outcrop, where the rock is fissured, it is necessary to leave large pillars. As stated above, some of the uppermost layer is left in the roof but it is believed that eventually much of this can be recovered. Occasionally some roof stone falls and it is necessary to use some timber.

Over part of the tract a bed of coal about 60 feet above the limestone was formerly worked.

The company sees the approaching exhaustion of the limestone in the hill now being worked and has recently reopened the Cambrian mine in an adjoining hill due west and across Wampum Run. The stone is similar to that now being obtained in the Crescent mine. Some of the stone now mined comes from nearly a mile from the portal. The crusher is near the mouth of the mine and the crushed product is conveyed about one-fourth mile by bucket tram to the mill. The dry process is used. There are six kilns. The capacity of the plant is 5000 barrels per day.

Shale is usually required and comes from the same hill as the limestone.

Analysis of shale at Medusa Portland Cement Co. quarry

CaO	1.25
MgO	1.00
Al_2O_3	19 to 20
Fe_2O_3	9 to 10
SiO_2	61 to 62
Alkalies	1 to 1½

It is common to use a small amount of sandstone. This is also obtained from the same hill and analyzes about 96 per cent silica and 2 per cent Al_2O_3 and Fe_2O_3.

The following analyses have been furnished by the company.

Crescent mine of the Medusa Portland Cement Co., entry No. 6, sampled June 1, 1929

	Gray	Bull	Rotten	Blue	Bottom Blue	Total face
Thickness	48″	20″	14″	36″	48″	176″
						Average
CaO	51.58	46.78	22.24	44.48	47.70	45.26
MgO	.85	1.53	1.53	.88	.72	.96
Al_2O_3	1.61	3.66	10.53	2.22	3.47	3.82
Fe_2O_3	1.05	1.70	5.25	2.20	1.75	1.93
SiO_2	3.42	7.76	39.06	9.86	6.12	9.13
Loss	41.00	37.34	20.40	35.76	38.48	36.95
Total	99.51	98.77	99.01	95.40	98.24	98.05
$CaCO_3$	91.51	83.20	39.10	79.60	86.15	80.82

Pounds of shale per 100 pounds of limestone, 493.
Mix figured as 77 pc. $CaCO_3$.
About half of the gray is left as roof and not included.

Crescent mine outside, by entry No. 2, April 2, 1929

	Gray	Bull	Rotten	Blue	Total
Thickness	78″	18″	42″	99″	237″
					Average
CaO	50.19	47.91	46.72	50.90	50.29
MgO	1.05	0.72	1.02	0.87	0.91
Al_2O_3	1.34	5.15	4.04	1.42	1.99
Fe_2O_3	1.07	1.27	1.10	0.90	1.27
SiO_2	3.10	5.90	8.26	9.28	4.62
S			not	determined	
Loss	41.90	38.86	38.26	40.94	40.54
Total	98.65	99.81	99.41	99.31	98.67
$CaCO_3$	89.60	85.52	83.40	90.86	89.78

16.6 pounds shale to 100 pounds limestone.
Mix 77 pc. $CaCO_3$.

Cambrian mine, main heading, March 21, 1929

	Top Gray	Bottom Gray	Rotten	Top Blue	Bottom Blue	Average
Thickness			not	given		
CaO	52.38	49.86	31.05	45.33	49.56	46.64
MgO	0.72	0.78	1.23	0.77	0.72	0.82
Al_2O_3	2.38	2.56	11.82	5.42	2.86	4.45
Fe_2O_3	0.50	0.60	2.20	0.90	0.60	0.87
SiO_2	3.46	4.96	26.22	10.16	5.24	8.78
S			not	determined		
Loss	39.78	40.04	25.74	36.36	39.90	37.28
Total	99.42	98.80	98.26	98.94	98.88	98.84
$CaCO_3$	93.50	89.00	55.42	80.94	98.46	83.25

8.1 pounds shales to 100 pounds limestones—mix 77 pc. $CaCO_3$.

The Consolidated Stone and Mining Co., controlled by the New Castle Lime and Stone Co., is operating a mine in Wayne Township nearly due east of the Medusa Portland Cement Co. about 1¼ miles southeast of Chewton. The Vanport limestone here was formerly obtained by open quarrying but when the overburden increased to 50 feet, underground mining was started and is now being followed exclusively. The cost of production was cut and cleaner stone obtained. In mining the company takes out the stone in 30-foot haulage ways and leaves 30-foot pillars. Usually the upper 2½ feet of stone is left in roof.

Section at Consolidated Stone and Mining Co.'s quarry

	Ft.	*in.*
Shale		
Thin layer of iron ore		
Gray limestone, left in roof	2	6
Gray limestone, shot down after being drilled by stoper drills following the removal of the blue stone below	5	
Shaly limestone, Bull layer	1	6
Blue stone, somewhat shaly at top, massive below	14	6

The company burns lime in two kilns on the property. The lime is used both for agricultural purposes and in building construction. Coal is obtained from a 28 to 30 inch coal bed lying about 35 feet above the limestone. The company also markets all sizes of commercial crushed stone.

The Duck Run quarry, operated in 1929 by Schrecongost Coal and Lime Company, of New Castle, is in the northern end of Wayne Township, about one mile south of Duck Run. It is situated in the hillside to the east of the road between Duck Run and Hazeldell.

The quarry face is about 500 feet long and has been worked back into the hill until considerable overburden has been encountered. Mining operations have been begun at the point where overburden is heaviest, but open face quarrying is still resorted to under lighter overburden. The mine extends for a distance of 35 to 40 feet under the hill. At this point a room is being turned off. The limestone is about 17 feet at the portal of the haulage way, of which a five foot top ledge is being left as roof.

The company formerly burned the stone for lime but the two kilns have been abandoned and crushed stone is supplied to the Pittsburgh, Harmony, Butler, and New Castle Electric Railway, whose right of way passes within a few hundred feet of the face. Some of the stone is being ground for agricultural lime which they sell with an analysis of $CaCO_3$—91.67 per cent, and MgO—1.63 per cent; fineness 50 per cent through 100 mesh. It is also probable that some of the limestone is sold for mine dusting.

The Vanport is of a lighter chocolate color than in the areas previously described, and is also less crystalline. The top of the formation is well marked by a layer of limonite which is about 6 inches thick, passing upward into a massive and solid bed of limonite of about the same thickness. A thin zone of oolitic material was found associated with the limonite but it could not be found in place.

The company is using a gyratory crusher and an Allis-Chalmers pulverizer.

The Rose Point quarry is located on the southwest slope of the hill directly south of Rose Point. The Vanport limestone is readily separable into an upper laminated, next a massive bed, a lower laminated band, and a solid massive bed at the base.

The Vanport reaches a thickness of 18 to 20 feet, although the topmost layer, distinctly reddish in color and grading into the overlying limonitic layer, is not worked. It is of interest to note that the limonitic top covering of the Vanport in this vicinity supplied the iron ore for the Milroy and Hope Furnaces approximately 60 years ago.

The limestone is darker in color on fresh surface than that found in the Lehigh Cement Company quarries at New Castle. It varies in color from a chocolate gray to a bluish gray, both types altering on surface exposure to a dove color.

Cave material is rather abundant on the exposed faces of the quarry. Numerous fine specimens of aragonite, some of which show fibers eight inches long, were seen. Toward the west end of the quarry some rather large clay seams are encountered near the base of the limestone. The Vanport is here quite fossiliferous.

At the time of the visit in 1929 only two of the ten vertical steel kilns were being operated. Most of the lime quarried is sold as hydrated lime for fertilizer although some finds use as plaster, lump lime and ground as unhydrated lime. At one time, it is reported, stone from this quarry was sold for fluxing purposes.

Adjoining this tract on the south is the farm of Mr. J. Stuart Brown, Wayne Iron Works, Pittsburgh, Pa. On this farm much mining was done for the iron ore but the limestone was left intact. The cover here on the limestone is relatively light and there are many acres of ground (20-40) that offer an especially attractive field for limestone quarrying. A spur from the Bessemer and Erie R. R. has been constructed to the quarry and lime kilns.

QUARRIES NOT IN OPERATION

Vanport limestone outcrops on the farm of Mr. Stoner three-fourths of a mile west of Rose Point, under light cover. A quarry could be opened here to advantage, in fact the rock has already been quarried in a small way and ground for fertilizer. The limestone is 1200 feet above sea level.

In the eastern part of the county, near the head-waters of Jamison Run, the limestone crops in the bed of the stream.

One mile northwest of Plaingrove it outcrops on both sides of Taylor Run. The ledges are 5 to 6 feet thick but the total thickness could not be ascertained. The elevation of the limestone here is 1180-1200 feet.

One and a quarter miles northwest of the former locality, on the farm of Mr. N. A. Offett, the limestone crops out in the field southwest of the house and has been quarried for burning. Six feet of hard gray rock is exposed in a recent opening. The limestone was also quarried on the farm of Mr. T. M. Gealey immediately west of the Offett premises, but it is thin here and appears to be mostly eroded. Clay seams in the limestone are numerous. The swampy areas lie on or just beneath the limestone.

About 1 mile south of New Castle is the old quarry of the Shenango Limestone Co. The concern supplied stone for flux, ballast, and roadmaking. The quarry face is 2500-3000 feet long. The limestone here is 20 to 22 feet thick and was quarried in two benches. The upper bench consists of about 12 feet of gray limestone, the lower 4 or 5 feet of which is thin-bedded. This upper bench has been quarried in the past, chiefly for flux. The lower bench, which is about 5 feet thick, is blue, exhibits the usual irregular bedding of the lower part of the Vanport limestone, is hard and knotty and not suitably for flux, hence has been left in the bottom of the quarry to be quarried later from time to time for ballast or road metal.

The cover on this limestone is 35 feet thick at the deepest point. Toward the north end of the quarry it is much thinner, diminishing to 10 or 15 feet of disintegrated sandstone and shale, and is in places even thinner, so that there is a considerable area here that could be easily and inexpensively stripped.

All of the beds in this quarry seem of suitable character for road building.

Three-fourths of a mile northeast of New Castle Junction, on a farm of 50 acres owned by a Mr. Cooper is an old quarry, formerly leased by the Geo. W. Johnson Limestone Co. Immediately to the south there are from 10 to 12 acres of ground underlain by the limestone, which has been thoroughly tested and is said to be of good quality and thickness. In the old quarry but 8 or 10 feet of the limestone are exposed, the base of it being concealed by debris and water which has been dammed in to furnish water for stock.

Much of the adjacent territory to the north still is underlain with the limestone.

North of West Pittsburgh, the limestone outcrops 1040-1060 feet above sea level, and one can see 8 feet of the rock, which is not its entire thickness. There is a small opening in it.

Just east of West Pittsburgh is an old quarry that has not been in operation since 1911. The quarry face is 250-300 feet long and exposes a thickness of 20 feet of good limestone. The cover for a distance of 200 feet back from the quarry face varies from 15 to 30 feet in thickness and consists of soft disintegrated sandstone and sandy shales. The elevation of the beds here is 1060-1080 feet. One foot of the inferior iron ore occurs above the limestone. The limestone outcrops to the north along the hillside for some distance from the quarry.

Half a mile south of Union Valley an outcrop of the limestone shows a thickness of 23 feet. This is the maximum for the Vanport limestone in Lawrence County, so far as observed.

Half a mile northeast of Chewton are the old quarries of the Lawrence Limestone Co., previously owned and operated by the Geo. W. Johnson Limestone Co., New Castle, Pa. These quarries which are extensive, have not been operated for 20 years and the spur from the Baltimore & Ohio R. R. has been removed. The old quarry face exposes the limestone for 1000 feet or more, the average thickness being 12 to 14 feet.

The cover, which at the quarry face is 15 to 40 feet thick, increases rapidly up the slope of the hill to 70 feet at 200 feet from the quarry face. This rapid increase in cover was probably the reason for the abandonment of the quarry. Coal has been mined from a bed 80 to 90 feet above the limestone.

Half a mile northwest of the previous locality is another old quarry of considerable extent. The limestone here is 15 to 20 feet thick. The upper 10-12 feet has been quarried, probably for flux; much of the lower bench, 5 feet thick, which consists of hard blue limestone, has been left in the quarry floor, and would be available for road metal. This rock extends back under the old waste heaps, where it could be easily recovered. The cover over the limestone here is 25-30 feet thick and consists of thin bedded sandstone.

Half a mile east of Newport is the extensive quarry of the Interstate Limestone Co. The limestone is exposed in the quarry face for half a mile along the west slope of the hill, and has a thickness of 17-20

feet. Three benches are distinguishable, all apparently suitable for road material. The usual gray and blue varieties of limestone are typically developed.

Eastward from the northwest end of the quarry, around the end of the ridge, there seems to be a considerable acreage of good stripping ground, where the cover would be light. At the southern end of the quarry considerable rock has been stripped.

One mile north of Chewton are the old extensive quarries of the Pittsburgh Limestone Co. and the Lawrence Limestone Co. The quarrying operations of the two companies developed one continuous quarry face about 1¼ miles long. The two quarries were under one management, the Lawrence Limestone Co.

At the south end of these quarrying operations the elevation of the limestone is 1020-1040 feet; but northward it rises rapidly to 1060-1080 feet.

At the south end the limestone is 18 to 20 feet thick and consists of two benches, the upper 12 feet being gray and the lower 6 blue. At this end of the quarry for a stretch of 1500 feet along the quarry face, the rock is too highly siliceous for flux. The rock, however, is perfectly suited, as it seems, for road metal. There are 30 to 40 acres of ground that could easily be stripped and quarried, and hundreds of thousands of tons of rock already broken or ready to be quarried so that this place is one of the very attractive points for immediate supply. The cover along the quarry face is 20-30 feet thick and increases to 50 feet, 200 feet back from the quarry face.

At the north end of the quarry the rock is suitable for flux, the upper 12 feet of gray limestone having been shipped for flux in Bessemer furnaces, while the lower 6 feet of blue rock was used in open hearth furnaces. All the rock from this part of the quarry was sold for flux, most of it being shipped to Sharon and East Johnstown.

North and northwest of Hazeldell there are many outcrops of the Vanport limestone. Small quarries have been opened in several places.

On the farm of Mr. F. W. Cochran, 1½ miles west of Moravia, the Vanport outcrops in the field north and west of the house at an elevation of 1050 feet. This tract has been drilled by the Crescent Portland Cement Co. and 16 feet of limestone is reported.

On the farm of Mr. Kelso, 1 mile northwest of Moravia, the limestone outcrops again at an elevation of 1050 feet. The beds here seem to lie between 1030-1050. Northward from here on the farm of Mr. E. O. Duff, there is an exposure of 4 feet of limestone at about the same elevation.

On the farm of Mr. A. R. Bright, half a mile north of Kelso's farm, is an old limestone quarry, which 40 years ago was worked for flux. The quarry was an extensive one, extending to the north along the side of the hill. About 10 feet of gray rock was removed, leaving about 5 feet of blue rock in the bottom of the quarry. The total thickness is 15 feet or more. The cover at the quarry face is from 10 to 15 feet thick and consists of soft glacial debris. It slopes gently upwards to the west and 200 feet from the quarry face is but 20 to 25 feet thick.

On the State line, just north of the Mahoning River, is the old quarry of the Mahoning Limestone Co. This is a magnificent quarry and an extensive one. The limestone is about 18 feet thick and of the usual two varieties, gray and blue. The cover consists of glacial drift. The surface of the limestone is beautifully glaciated, the striae running

S. 30°E. All of the product of this quarry was shipped for flux. This includes both the gray and the blue limestone, so that no bottom rock was left in the quarry. The crusher was located on the B. & O. R. R. south of the quarry and prepared 1000 tons daily.

One mile east of Robinson is a nearly level area of 100 acres or more, formerly underlain by the limestone, which here had a thin cover of rock and glacial debris. The gray limestone has been quarried from nearly all of this area, but the blue limestone was left in the quarry floor. There are places where 6 feet of blue limestone can be seen under the debris and it seems probable that the entire area is still covered with this blue rock, although this could not be positively determined.

Conditions are similar in an area about 1½ miles northeast of Robinson. Here we have what was an outlier of the Vanport limestone, under very thin cover, from which most of the gray limestone has been quarried for flux, leaving the blue rock in the bottom of the quarried area. There are from 2 to 4 feet of this blue limestone still visible over most of this tract.

Another isolated patch of the limestone, which is intact, lies 2½ miles north of Robinson. Much of this virgin patch of limestone lies on the farm of Mr. Arthur Wright. Here an opening shows 14 feet of good limestone, the upper 12 feet being gray, with 2 feet of blue rock below. On this farm 18 to 20 acres are underlain by the limestone. The adjacent farms to the northwest are in part also underlain by it.

Throughout the entire southwestern corner of Lawrence County, which is deeply covered with rock debris, few exposures of Vanport limestone seem to exist, and limited time did not permit a careful search for them. In the open valley of Little Beaver Creek about Enon Valley, it apparently lies close to 1000 feet above sea.

Northward in the valley of Beaverdam Run and Honey Creek it has an elevation or 1040-1060 feet. From here it rises gently to the north.

One mile northeast of Eastbrook at an elevation of 1140-1160 the Vanport limestone outcrops along the south slope of the hill. Here on the farm of Mrs. H. M. Wilson, 106 acres are underlain by the limestone. Only 6 to 10 feet are visible, mostly gray limestone. The entire thickness could not be ascertained. The cover is very light, being only 4 to 10 feet of glacial debris.

Analyses of Vanport limestone of Lawrence County made by Second Geological Survey of Pennsylvania

	1	2	3	4
$CaCO_3$	94.785	94.214	93.340	95.768
$MgCO_3$	1.369	1.732	1.460	1.097
Al_2O_3	1.187	.805	1.563	.632
S	.123	.165	.123	.088
P	.032	.020	.047	.017
Insoluble	2.080	2.790	3.070	1.970
	99.576	99.726	99.603	99.572

1. Moffit's quarry, 2 miles north from Croton. Compact; brittle; sparkling with calcite; bluish gray and pearl gray; with irregular fracture. (3, p. 297)

2. L. K. Shinn & Bros.' quarry, near Wampum, Big Beaver Township. Compact; brittle; sparkling with calcite; bluish gray. (3, p. 297)

3. Green, Marquis and Johnson's quarries, near New Castle. Compact, brittle; sparkling with calcite; bluish gray, with irregular fracture. (3, p. 298)

4. McCord's quarry, 3 miles northwest from Mt. Jackson, North Beaver Township. Compact brittle; sparkling with calcite; pearl gray, with irregular fracture. (3, p. 298)

FREEPORT AND BRUSH CREEK LIMESTONES

Lower Freeport limestone. The Lower Freeport limestone has not been noted in Lawrence County although it may be feebly developed in some places inasmuch as both underlying and overlying strata are present.

Upper Freeport limestone. The Upper Freeport limestone is developed locally in the southeastern part of Lawrence County but was not investigated by the writer. Near Camp Run it is said to be 5 feet thick and to have been quarried and burned for lime at one time. "It is a very hard, compact and bluish-gray rock, breaking with sharp conchoidal fracture, and having its surface frequently stained reddish with iron. It burns into a tolerably fair lime, but great care is required in the process to get it to slack well" (2, p. 79).

Somewhat north of the center of Perry Township, the Upper Freeport is 7 feet to nearly 10 feet thick but interstratified with laminae of fire clay.

Brush Creek limestone. A thin limestone of no economic importance which may be the Brush Creek limestone has been reported in a few localities in Lawrence County.

CALCAREOUS MARL

J. B. R. Dickey, in a brief report on the calcareous marls of the State published as Mim. Bulletin 76 of this Survey, describes the following occurrence in Lawrence County.

"On the farm of Mr. Andley Boak, New Castle, R. D. No. 6, on the Princeton-Harlansburg road, occurs a terrace formation of brown marl beneath a spring which emerges about 10 feet above the level of a stream. This marl analyzes about 60 to 65 per cent carbonate. Mr. Boak has used this marl on his own farm for a number of years with excellent satisfaction, hauling it directly from the bank and spreading from the wagon or heap at the rate of 6 to 8 loads per acre on land plowed for wheat."

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LEBANON COUNTY

CAMBRO-ORDOVICIAN LIMESTONES

The Cambro-Ordovician limestones cut across Lebanon County in a band about 8 miles wide at the Berks County line and gradually narrowing west of Lebanon to about 4 miles at the Dauphin County line.

The limestones of the Lebanon Valley are readily divisible into three groups, and these in turn on the basis of fossils and minor lithologic characteristics will probably be still further subdivided. The oldest limestones of the county to be differentiated belong to the Tomstown group of the Cambrian which is sparingly represented in the vicinity of Newmanstown. They consist of dolomitic limestones with more or less interbedded shaly strata. Elsewhere in the county, the Tomstown limestones are concealed by the Triassic shales and sandstones.

The Conococheague limestones, of Canadian* age, overlie the Tomstown. These occupy the greatest area of any of the limestone formations of the county. Except near the western boundary of the county where they appear to be absent, they constitute the surface rocks over the southern half of the limestone belt. They consist of dolomitic limestones of different grades of purity. They have been quarried in the past but not to any large extent in recent years, except in connection with the Cornwall iron ore mining operations. It is of interest to know that these dolomitic limestones are the ones which have been intruded by a diabase dike at Cornwall and converted into iron ore by substitution of iron oxides for the carbonates.

The Beekmantown limestone of Canadian age constitutes the next younger formation. These limestones outcrop in a band about a mile in width except near the western boundary of the county where they constitute all of the limestones of the valley with the exception of a narrow band on the north. As has been described in other counties, the Beekmantown limestones vary greatly in composition. Some beds are practically pure limestone carrying only 1 or 2 per cent of $MgCO_3$ and others are high enough in magnesia to be called dolomite. These high and low magnesian limestones are interbedded so intimately that it is difficult to find a place where either kind can be quarried separately. Many layers of the Beekmantown present typical characteristics on weathering. On a fresh fractured surface the stone may appear to be uniform in texture and composition but on a weathered surface it appears to be thinly bedded with the individual laminae somewhat different in color and discontinuous, or the surface may appear blotched with sandy patches in a matrix of finer material. Differential weathering produces a rough or pitted surface.

The next younger limestone formation occupies a narrow band at the north edge of the limestone valley next to the Martinsburg shales, beneath which it dips out of sight. It is within this belt that the band of high grade limestone, known commercially as the Annville limestone and described below, is found. Besides this good limestone, this highest group contains siliceous and magnesian limestones. Some of these impure limestones are argillaceous and high in carbonaceous matter, thus giving them a very dark color.

* The author prefers the U. S. Geological Survey classification which places this group in the Cambrian and the Beekmantown in the Ordovician.

Structure. Great compressive forces have folded the strata and overturned them to such a degree that the beds in much of the region have a prevailingly southern dip. The dip of the beds varies greatly from place to place. The general direction of strike is roughly east-west but naturally there are many variations in a region that has been folded as intensely as this one.

In the region between Myerstown and Lebanon there are at least two small areas where the rocks have been folded downward into overturned synclines and by erosion appear as canoe-shaped isolated basins.

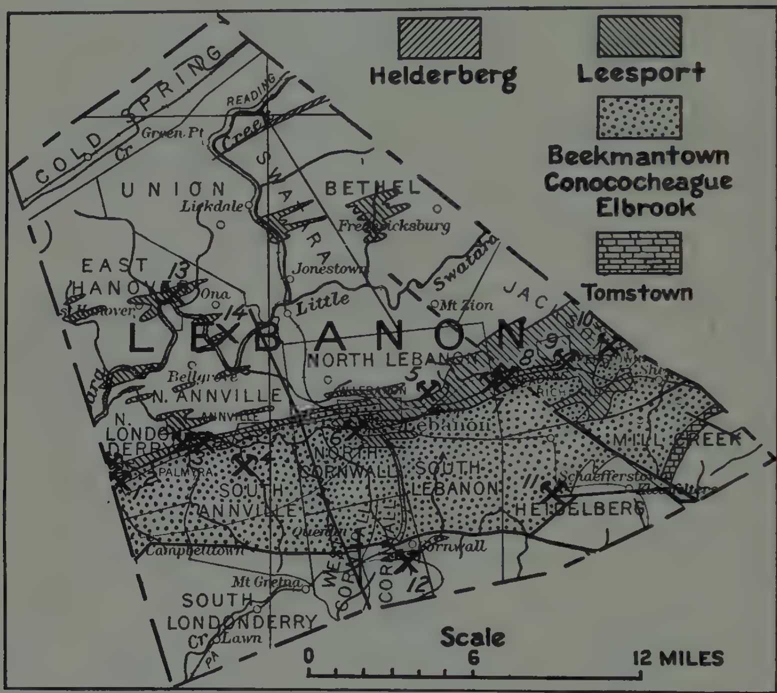

Fig. 22. Limestone areas in Lebanon County.

1. Walter Wood. 2. Henry K. Smith. 3. H. E. Millard. 4. Becker Bros. 5. Wagner's Clay Pit. 6. Donaghmore Coal and Stone Co. 7. Calcite Quarry Corp. 8. Bethlehem Mines Corp. 9. John Ebbing. 10. H. E. Millard. 11. Frank Horst. 12. Iron mines of Bethlehem Mines Corp. 13. Benjamin Hauer. 14. Elmer Fortney.

These are in the properties of the Calcite Quarry Corporation and the Bethlehem Mines Corporation and have only been interpreted by data obtained by quarrying and by prospect drilling. It is probable that there are many other occurrences of this kind.

There is very little displacement of the beds by faulting in comparison with what one might expect in a region so much folded. Faults have not proved to be serious obstacles to quarrying.

Uses of Lebanon County limestones. In the past when the principal use for the limestones was for the manufacture of agricultural lime, with minor uses as flux for the local iron furnaces and for building stone, scores of limestone quarries were opened throughout the

region. The quality of the stone was always considered but was of less consequence than its proximity to the consumer. At present the only quarries in continuous operation are those that furnish superior stone for flux and cement and are located near the railroad. Merely by accident, the Reading Railroad passes through the area containing the best stone of the region, stone of such unusually fine quality that railroad facilities would doubtless have been provided if the main line of the railroad had been located elsewhere.

Most of the limestones of the region are high in magnesium carbonate as well as silica and hence of little value for flux, cement, or high grade lime. They are well adapted for concrete and road metal and have been quarried for such use near Lebanon and the other towns of the district. They would be valuable for building purposes if the cracks, joints and uneven bedding planes were less numerous. As an illustration of the demand for high quality stone only, it may be mentioned that at Cornwall the Bethlehem Steel Company is working an extensive deposit of magnetite iron ore by the open cut method which requires the removal of large quantities of overlying Cambro-Ordovician limestones of average quality. Occasionally some of the stone is sold for local use on the roads or for concrete but in the main the stone is wasted because of lack of market.

Annville limestone. The only section of this region worthy of special discussion is the area of high grade limestone that extends as a narrow band from Millardsville to Palmyra. The best limestone of the district, and of its kind the equal of any in the State, is contained in a belt only a few hundred feet wide. It parallels the Harrisburg-Reading road, lying a short distance to the south and extends from the Berks County line just southeast of Millardsville westward to near Avon beyond which point it can not be traced. It is not quite continuous, due to the folding and subsequent erosion described above. For most of this distance, the outcrops are near Tulpehocken Creek which is a decided obstacle in opening quarries. Appearing again just east of North Lebanon, it passes through the north part of the town and thence westward, passing a short distance north of the towns of Cleona, Annville, and Palmyra to the Dauphin County line and beyond. In this area limestone somewhat less than 400 feet thick averages about 95 per cent calcium carbonate. This stone has been quarried most extensively in the vicinity of Annville and consequently the name "Annville limestone" has become a trade name for the product of the entire belt.

The best grade Annville limestone is a soft, light gray stone which breaks readily with a smooth glassy fracture. In a few openings a darker blue variety is almost as high in $CaCO_3$. The contrast between the underlying black, slaty, siliceous rock and the overlying dolomitic limestone is so striking that the separations are easily made.

The high calcium stone, which is a soft, light gray, crystalline limestone, lies between dolomitic strata above that are generally higher in silica, and black slaty, siliceous rocks below. For certain uses, some of these other stones may be included in a shipment and this must be borne in mind in the examination of the analyses that follow. Adjoining the quarries of the best stone, there are in places other quarries whose specifications are less rigid. H. E. Millard, the largest operator of the district, claims that all his quarries contain limestone with 98

per cent or more of calcium carbonate, although analyses of the shipments from the quarries of the belt seldom show material of this quality. With sufficient care in quarrying, most of the producers could ship stone averaging more than 96 or even 98 per cent calcium carbonate.

The stone from the region is sold principally to the Portland cement companies of the Lehigh district that require some high grade calcite stone to mix with the cement rock of their quarries that is slightly deficient in its $CaCO_3$ content, and to the iron and steel companies of the State. Considerable is burned for lime and a small quantity is used as crushed stone. The early use for the stone was almost entirely for blast furnace flux and for high grade lime.

The chief obstacles in quarrying this desirable limestone are the presence of water at comparatively shallow depths and the overburden of residual clay which extends downward in holes forming bad clay pockets. In some places the strata are so shattered and cavernous that any quarry opening receives the drainage from several acres and few are so located that they are self-draining. Accordingly the necessary pumping considerably increases the cost of operation. The overburden is of variable thickness and in some localities is too thick to warrant removal at the present time.

DESCRIPTION BY DISTRICTS

Many quarries have been opened in the county that are not of sufficient importance to justify separate descriptions in a general volume of this character. In 1886, d'Invilliers (see bibliography at close of chapter) located and described 43 limestone quarries. Some of these, especially in the vicinity of Annville, are still in operation although nearly all have been abandoned. Since the high grade limestones only are of much importance at the present time, little attention will be given to the others. Suffice it to say that almost any of the limestones of the county are suitable for crushed stone or for agricultural lime. The location and the ease with which the stone can be obtained and marketed are the determining factors governing the further development of the limestones generally.

Palmyra Area. The most westerly operation in the Annville limestone in Lebanon County is the Walter Wood quarry about three-fourths mile northwest of Palmyra. The strata dip steeply to the south with an east-west strike. At the north side of the quarry black slaty stone is exposed with dolomitic limestone forming the south hanging wall. Not much more stone is to be gotten from this quarry by open cut working without removing much waste stone. The heavy clay overburden has prevented much work ever being done here. This quarry is just across the road from the Bradley quarry of H. E. Millard which lies within Dauphin County. From the Wood quarry eastward there are no openings in the band of Annville stone until the quarries of H. E. Millard are reached about 2½ miles distant.

In the west part of Palmyra, Henry K. Smith is working a quarry in the Beekmantown limestone for crushed stone. This quarry was in operation in 1886 to obtain stone for lime burning and building construction. At present a small amount of building stone is produced but almost all is crushed for road purposes. Some of the screenings are sold to a concern making building blocks. The quarry covers a

large area, about 300 feet wide and 700 feet long, with a face from 30 to 35 feet high. Several different varieties of stone are exposed in the quarry. High-calcium, gray, crystalline limestones are interstratified with dark-colored magnesian beds. Some of the limestones are very thin-bedded and a few strata are decidely shaly. Many of the high magnesian beds have been greatly fractured and the cracks later filled with calcite, dolomite, and quartz veins. Some of the dolomitc vein matter is colored a pale pink. In general the strata dip to the south at low angles, but a number of folds are exposed. Some of the structures are very complex. The capacity of the quarry is 500 to 600 tons per day. There are numerous bad clay pockets. The size of the quarry is such that a new deeper cut can be made in the bottom of the quarry and when this is done fine clean stone can be produced at low cost, since the clay deposits do not extend to the level of the present quarry floor.

Annville Area. The most important limestone quarrying in Lebanon County is centered about Annville. The quarries yielding the best stone lie to the north, northwest, and west of Annville. When d'Invilliers (see bibliography) made his investigations in 1886, there were 10 quarries in that section, all of which he described. Some of these are now idle, but others have been in more or less continuous operation ever since. The regular band of "Annville limestone" parallels the Reading Railroad and lies a very short distance to the north. Due to minor folds, this same band is present to the south of the railroad just west of the town as well. There are some complicated structures in that section which the writer has observed but has not had opportunity to investigate sufficiently to reach a definite conclusion concerning them.

At one time the Vulcanite Portland Cement Co. operated a quarry just south of the railroad on the north side of Quittapahilla Creek and the Lawrence Portland Cement Co. had two quarries, one on each side of the Harrisburg-Reading road just west of Annville. The two quarries of the latter company were connected by a tunnel passing beneath the highway. These quarries, as well as those in the regular band lying to the north of the railroad now belong to H. E. Millard. He has altogether 11 quarries, active and inactive, in this locality.

The main Millard quarries lying to the north of the railroad extend almost continuously for nearly two miles and are connected by open cuts or by tunnels. The drainage of these large openings has been an expensive matter because Killinger Creek cuts across the properties and on the east the quarries come close to Quittapahilla Creek. To prevent water from these streams entering the quarries, the channels of both have been concreted for several thousand feet altogether. Nevertheless, the cavernous character of the rock permits a large amount of water to enter the quarries. The water from all of the quarries is drained into one sump and is then pumped to the surface, a height of about 125 feet. The amount of water pumped varies from 4,000 to 10,000 gallons per minute. Previous to the concreting of the stream channels, it sometimes was as much as 25,000 gallons.

A striking example of limestone decomposition is exhibited in the quarries of H. E. Millard once owned by the Vulcanite and Lawrence Portland Cement companies, a short distance west and northwest of Annville, on the south side of the railroad. In these quarries there

are areas where pure, compact, high-grade limestone has been completely changed to a fine pulverulent powder which, by slight crumbling in the hand, can be made to pass through a 200-mesh screen. The areas of decomposition are irregular, ranging from 20 to 200 feet in diameter, and extending downward to a proved depth of 70 feet in some places. The bedding and joint planes can be seen in the decomposed material and can be traced into the unaltered beds of limestone with no apparent distortion or displacement.

An entirely satisfactory explanation for this phenomenon has not been found as yet. Microscopic examination has shown that solution has apparently removed the exterior of the minute crystals of $CaCO_3$ constituting the rock, but why the solution penetrated the rock and dissolved portions throughout and not along the circulation channels is not apparent. The present position of the strata and the topography do not indicate that ground water would remain stagnant in these places for such a period of time that the rocks became thoroughly saturated with ground water whereas the other areas adjoining were not, but it is possible that at some time in the past this might have been the case.

This chalky material which contains from 96 to 98 per cent $CaCO_3$ has been used somewhat in the manufacture of Portland cement, although it is difficult to handle, and now is being quarried, bagged and shipped for agricultural purposes. After being dug by steam shovel, the material is put through a crusher to break up the larger lumps. It is then passed through a screen that separates all of the lumps larger than 1½ inches in diameter. These go to a hammer mill for further breaking. It then goes to a rotary drier and afterward to a Bethlehem pulverizer which reduces it to a fineness of 95 per cent through a 200-mesh screen. A separation of some material fine enough to pass a 325-mesh screen has been made. When first offered to the farmers for fertilizing, there was little demand as previously only burned lime had been so used. The value of this unburned product is now being appreciated and the demand is steadily increasing.

The Millard quarries at Annville are all very well equipped for producing large tonnage of prepared stone to meet different requirements. The bulk is shipped to the cement plants of the Lehigh Valley. At one time it was used principally for fluxing stone. Pulverized stone to the amount of 62,000 tons a year has been produced.

North of the railroad and east of Quittapahilla Creek, there is an old quarry showing some high grade limestone dipping steeply to the north. To the northwest of this opening there is a small quarry of black shaly limestone that has been worked for crushed stone.

Becker Brothers are operating a quarry for crushed stone in the west side of Quittapahilla Creek about one-fourth mile south of the Harrisburg-Reading road. The stone worked belongs to the Beekmantown group and consists of interbedded soft, light gray, high-calcite stone and harder, dark blue, magnesian stone. There are numerous veins in places. The general dip is to the south, but there are numerous small folds. The beds are massive. There are a few clay pockets. The quarry is about 250 feet long, 150 feet wide, and has a face about 40 feet high. The capacity of the plant is about 150 tons per day.

On the east side of Annville, there are 2 quarries on either side of the road that show Beekmantown limestone. They contain interbedded

high and low magnesian strata. These have been worked for crushed stone and for burning lime.

Lebanon Area. The band of Annville stone evidently passes through the north part of Lebanon, but there are few exposures and no active quarries. At the Lineaweaver quarry, a short distance northwest of Lebanon, stone of the Annville type is reported to have been quarried. From the dump the writer has obtained some pieces that appear to be of that variety.

In Wagner's clay pit about three-fourths mile north of Avon, some limestone has been quarried that likewise resembles the Annville stone. The clay is dug for brick and the underlying stone burned for lime.

In the outskirts of the town of Lebanon, west, south, and east portions, there are at least 15 old quarries. These were most active at an early day when numerous blast furnaces were in operation, the quarries in several places being located close to the furnaces and furnishing the necessary fluxing stone. Some of these are of large size and were worked for many years. Lime was also produced from stone obtained in a number of these quarries. The lime was used extensively in masonry and for plastering as well as for agricultural purposes. A rather large amount of building stone was also obtained from some of these quarries. Most of the stone quarried in this section comes from the Beekmantown formation and is a mixture of high and low magnesian stone. In some of the quarries the dips are low and in places the beds are almost horizontal. Within recent years there has been little demand for stone in this region of the quality that can be produced except for crushed stone for concrete construction and for the highways. Almost any of the quarries in this area could furnish suitable stone for this purpose. The most active operator at present is the Donaghmore Coal and Stone Co., with its quarry at 16th and Walnut Sts., just north of the Fair Grounds. The quarry is about 600 feet long, 250 feet wide, and has a face averaging about 45 feet high. The stone belongs to the Beekmantown formation and consists of a soft, light gray, high-calcite stone and hard, gray to blue magnesian stone, much of which contains many gash veins filled with calcite, dolomite, and quartz. The beds are mainly massive and the stone comes out in large blocks requiring secondary shooting. The beds dip generally to the south at low angles, but there are several variations. In places, the strata are almost horizontal. Originally the quarry was used to furnish stone for flux and for lime burning. The high calcium stone was then sought. Now all of the product quarried is crushed for road work and concrete construction. The output is about 200 tons per day.

Myerstown Area. Next to the Annville region, the limestones in the region about Myerstown have been most extensively worked. The high grade limestones of the Annville type are present here due to synclinal folds and they now appear in canoe-shaped basins more or less separated from each other and from the main band by the removal of great masses of stone by erosion since the folding took place.

The most westerly operation in the Myerstown area is the new quarry of the Calcite Quarry Corporation on the south side of the highway (Route 422) about midway between Myerstown and Lebanon. With no outcrops in this property, which is known as the

Baney farm and under lease, the company had to explore by means of drilling. An extensive series of diamond and churn drill holes was put down to determine the character of the stone and its distribution. The quarry has been open only a few years and is still in the process of development. A large amount of high grade stone has been uncovered by the removal of a great quantity of clay. The band of good stone is about 200 feet in width and dips to the south at angles of 30° to 60°. The high grade stone has been found by a diamond drill hole to extend to a depth of 500 feet at least before it turns to come up. The high-calcium stone is fine grained, dense and generally bluish gray in color. The color ranges from white to almost black, but the composition varies less than the color. In the east part of the quarry there is a small secondary syncline that farther west merges into the main fold. Although there are reasons for believing that the hanging and foot walls are the same stratum, the chemical composition of the two as shown below are unlike so that they may be different beds. The stone in the hanging wall is characterized by its high magnesian content and the foot wall by higher silica. About 6 inches of black limestone containing much graphitic material is developed at the contact of the good stone and the foot wall stratum. The plant is well equipped throughout to furnish a large tonnage of excellent stone.

Typical analyses, Baney Farm, Calcite Quarry Corporation

	Hanging wall	*High calcium stone*	*Foot wall*
$CaCO_3$	61.60	97.03	81.45
$MgCO_3$	34.86	1.79	7.61
$Al_2O_3 + Fe_2O_3$	1.16	0.53	2.63
SiO_2	2.21	0.96	8.03
Specific gravity	2.74	2.80	
Per cent wear	6.4	4.3	
Per cent wear (washed stone)		3.6	
Toughness	10.0	14.0	

Just across the road to the east is the quarry of the Bethlehem Steel Co. Here the same band of stone quarried by the Calcite Quarry Corporation was worked for several years. The beds dipping to the south beneath the dolomitic beds caused the quarry to be narrowed as it deepened unless an increasing thickness of overburden was removed and the operation was finally abandoned. This deposit seems to spoon out toward the east thus furnishing evidence of the canoe shape of the body of stone.

A short distance to the southeast of the Bethlehem Steel quarry is the old quarry of the Calcite Quarry Corporation. S. B. Patterson, with whom the writer has made investigations in this region, has described the characteristics of that body of stone as follows. "In the pit one mile east of Prescott, which was recently exhausted by this company (Calcite Quarry Corporation) all sides of the canoe were exposed. The principal dimensions are: length—2450 feet, width at top and center, 350 feet, depth at center—125 feet, with both ends rounding up at the bottom and tapering off at the sides. The canoe was tilted 30 degrees from the vertical." The two sides of the syn-

cline were approximately parallel in the main body of the quarry, dipping to the south with an east-west strike. The western end of the canoe was determined partly by drilling. The east end is plainly shown as the beds in the trough of the canoe rise to the surface. Near the outcrop they show several small secondary folds.

Just southwest of Prescott, some quarrying of Beekmantown limestone has been done by Charles C. Weiss in two small openings to obtain stone for burning and for road metal. There are some small folds but in general the beds strike N53°E, and dip 27°SE.

In the region just west of Myerstown, several grades of limestone are exposed, some of high quality. Considerable prospect drilling has been done here but the relations of the different kinds to each other have not been determined. It seems probable that the structure is fairly complicated. The band of Annville stone appears to be absent in at least part of this region.

In a quarry between the highway and Tulpehocken Creek, about one-third mile northeast of the abandoned quarry of the Calcite Quarry Corporation, is a quarry that was worked to get stone to burn in 2 kilns that stand nearby. The beds strike N70°E. and dip 65°SE. The best stone which is of good quality seems to be about 100 feet thick. Considerable overlying dolomite has been taken out. Mud-filled seams are numerous in the stone.

Farther to the east and about 1½ miles west of Myerstown a quarry for ballast stone was one time worked. It is a hard siliceous and magnesian limestone of the type that normally underlies the Annville stone. It shows much graphitic matter along the bedding planes. The beds strike N75°E. and dip 34°SE.

For several years the Eastern Steel Co. worked the Bassler quarries about half way between the highway and Tulpehocken Creek. There are two openings which are now filled with water. The great expense involved in handling the water is said to have caused the company to quit. In the eastern opening the beds were approximately vertical with a strike of N73°E. The clay overburden was heavy. In the western part of the west quarry the strata dip south at an angle of about 20°. After the steel company abandoned these workings, a small concern continued to quarry those beds of high grade stone extending above water level to get stone for burning. A high quality of lime has been produced. In one place some black shaly rock was observed interbedded with the good limestone.

Along Tulpehocken Creek, just east of Myerstown, there are three limestone quarries. The one on the north side of the creek is owned by John Ebling and has been worked for crushed stone. The stone is mainly siliceous although there are some interbedded layers of high calcite stone.

On the south side of Tulpehocken Creek, John Ebling has worked two quarries under lease from H. E. Millard. The more westerly one is new but it has yielded some good stone that has been burned. The beds strike N68°E. and dip 18°SE. The other one is a large opening and has produced a large amount of good stone. Water said to be 50 feet in depth fills most of the quarry. The band of high grade stone dips beneath dolomitic limestones. The strata show some gentle folds but in the main dip gently to the southeast. The quarry was formerly worked solely for lime, but more recently the dolomitic

beds have been quarried for crushed stone and the high calcite beds extending above the water level for lime.

In 1925 the Lawrence Portland Cement Co. acquired several farms along Tulpehocken Creek about 1½ miles east of Myerstown and carried out an extensive program of prospecting by drilling. A few small openings where stone was once quarried showed stone of high quality and the drilling confirmed the company in the belief that a large amount of excellent stone could be obtained there. A quarry was started but abandoned when the properties were leased to the Calcite Quarry Corporation. Over much of the area, the structure of the strata seems to be regular but there are some complications.

H. E. Millard has two large quarries just south of Millardsville about 2½ miles east of Myerstown. The more easterly one is of large size due to the fact that the band of good stone, although somewhat folded, averages nearly horizontal. With the same thickness as found in the Annville region, or probably less, the outcrop covers a large area. The quarry east of the road was worked to a depth that caused much water to enter the opening. Believing part of this to come from Tulpehocken Creek, a new channel was cut and lined with concrete to divert the stream and to cut off water from this source. Due to the lack of demand for stone during the years 1931-33, the larger opening has been closed and allowed to fill with water. The opening west of the road is in the side of the hill and entirely above the level of the stream. In these two quarries the high grade Annville limestone is present and is underlain by black magnesian and siliceous beds. The former is the principal stone quarried. It is shipped to cement plants of the Lehigh Valley, used for flux and for crushed stone.

East of the Millardsville quarries there are numerous outcrops of high grade limestone and a few small abandoned quarries.

South and southwest of Richland there are several small quarries where the Beekmantown limestone was once quarried and burned for lime.

Southern Great Valley Area. The Conococheague magnesian limestones which constitute the outcropping strata throughout the southern portion of the limestone valley were once quarried at many points to obtain stone for lime burning and in some instances for flux for local blast furnaces and for building stone. Most of these quarries were small and have long been abandoned but the openings and old lime kilns can still be observed. They could be worked for crushed stone as the material is hard and almost everywhere of good quality for this use. In the west edge of Schaefferstown, Frank Horst is operating a quarry for crushed stone. In loading the stone, some blocks suitable for building use are put aside for that purpose. The most abundant stone is a hard, dark gray to blue, magnesian variety in beds from 2 to 8 feet in thickness. Interbedded with the high-magnesian stone there are some bands from 6 inches to 2 feet in thickness of soft white, banded or mottled, high-calcite marble. The beds are fairly regular and dip to the southeast at angles of 12° to 18°. The quarry is about 175 feet in diameter and the face about 35 feet in height.

At Cornwall the Bethlehem Steel Company quarries a large amount of Conococheague limestone in order to obtain the underlying iron

ore. Some of this stone has been crushed and sold for road purposes but most of it is wasted. The stone is hard and satisfactory for crushed stone but not desirable for many purposes. The following analyses furnished by the Bethlehem Steel Co. show the chemical composition of the stone.

Analyses of Cornwall Iron Mine limestones

SiO_2	17.50	12.80	4.10	6.22	4.35
$Al_2O_3 + Fe_2O_3$	3.60	5.50	1.64	2.54	2.35
$CaCO_3$	68.00	71.60	91.11	90.11	60.70
$MgCO_3$	10.80	9.80	3.25	1.05	32.45

1. White limestone, south side of mine.
2. Blue limestone, south side of mine.
3. Blue limestone, stripping, Middle Hill.
4. Blue limestone, southeast side of mine.
5. Dolomitic limestone.

MARTINSBURG LIMESTONE

Although practically all of the limestones of Lebanon County are included in the great limestone valley which crosses the county, there are a few limestones of lesser importance that deserve brief mention.

Within the great band of Martinsburg black and red shales forming the surface rocks in that portion of Lebanon County between the limestone valley and Blue Mountain, there are several places where thin limestone strata are interbedded with the shales. Where these limestones are few or very thin they are of no practical significance. In some localities, however, these limestone beds constitute more than half of the strata. In such places they have been quarried and burned for lime on a small scale.

At present the only known quarry operation in the Martinsburg is that of Benjamin Hauer located along the improved State highway about one-fourth mile east of Harpers Tavern. Throughout a thickness of a few hundred feet outcropping in the bluffs of Swatara Creek and nearby there are many limestone beds which have long been quarried on a small scale and burned for agricultural lime. The present operator has two kilns and burns from 2,000 to 6,000 bushels of lime each year. The lime is somewhat darker than the usual lime but the farmers in the immediate vicinity have long used it and are satisfied with the results obtained. There are two distinct types of stone. One is of conglomeratic character showing excellent examples of edgewise conglomerate on weathered surfaces. It is a gnarly stone, massively bedded. One bed over 5 feet in thickness was observed. The other variety occurs in thin beds rarely more than 6 inches thick. The stone varies in color from a light gray crystalline stone to a dense compact dark blue color. It evidently varies also in composition. It appears to be low in magnesia but high in silica. The beds mainly are almost vertical although the main opening shows some intricately folded beds.

Between Ono and Union Waterworks, Elmer Fortney has also quarried similar limestone within the Martinsburg within recent years to make agricultural lime.

ONONDAGA LIMESTONE

The Onondaga limestone is exposed in a very small, abandoned quarry on the east bank of Swatara Creek south of the first bend north of Swatara Gap.

HELDERBERG LIMESTONES

The Helderberg limestones are developed in a small band running east and west in the extreme north portion of Lebanon County. They are poorly exposed where Swatara Creek cuts across the band, but have not been observed much father west. They are of little importance in this county, although of great economic value in the central counties of the State.

Analyses of Cambro-Ordovician limestone of Lebanon County

	1	2a	2b	3	4	5	6	7	8
$CaCO_3$	89.55	92.24	94.44	93.86	93.92	94.66	95.78	94.20	70.50
$MgCO_3$	5.22	3.46	.90	1.94	3.67	3.17	2.46	2.89	13.34
SiO_2	3.56	2.00	2.52	2.57	1.27	0.84	1.05	1.37	10.57
Al_2O_3	1.84	1.26	1.56	1.57	1.02	0.97	---------}	1.14}	5.55}
Fe_2O_3	---------	.74	.55	---------	---------	---------			
S	---------	.046	.015	---------	---------	---------	---------	---------	---------
P	---------	.008	.005	---------	---------	0.004	---------	---------	---------

	9	10	11a	11b	11c	12a	12b	12c	12d
$CaCO_3$	71.27	73.20	59.06	41.93	66.70	78.13	80.68	82.20	81.76
$MgCO_3$	18.66	11.60	30.50	21.16	21.19	8.37	10.12	3.96	6.58
SiO_2	6.43	8.23	7.42	11.20	8.10	8.70	5.77	10.10	7.28
Al_2O_3 }	3.65}	6.93}	3.79}	25.40}	4.12}	1.94	2.13	1.58	1.97
Fe_2O_3 }						2.20	1.96	1.65	1.73

	13	14	15	16	17	18	19	20	21
$CaCO_3$	67.40	60.79	78.72	82.58	74.92	84.76	81.54	95.26	96.06
$MgCO_3$	22.93	34.44	17.60	11.49	17.49	10.50	12.55	2.97	1.68
SiO_3	6.48	3.12	1.85	3.59	3.54	1.56	3.10	.93	1.03
Al_2O_3 }	3.15}	1.82}	1.95}	2.25}	4.02}	3.22	2.83	.80	1.29
Fe_2O_3 }						---------	---------	---------	---------

	22	23a	23b
$CaCO_3$	81.10	84.37	95.67
$MgCO_3$	5.84	10.57	2.88
SiO_2	8.92	2.20	1.09
Al_2O_3	4.26	1.85	.72
Fe_2O_3	---------	0.55	---------
S	---------	0.033	---------
P	---------	0.008	---------

1. Property of Ephraim Erb, 1½ miles southwest of Richland. Average of 4 prospect samples.

2. Upper portion of Cambro-Ordovician limestones, Millard quarry, Myerstown. a) average of 209 cars shipped to Thomas Iron Co. during first half of 1920. b) average of 180 cars shipped to Thomas Iron Co. during latter half of 1920. Analyses by Thomas Iron Co.

3. Ebbling quarry, East Myerstown.

4. Bassler quarry, West Myerstown.

5. Upper part of Cambro-Ordovician limestones, Calcite Quarry Corporation, 1½ miles west of Myerstown. Average of 9 analyses made by the Robesonia Iron Co. between 1913 and 1921.

6. Millard quarry 2 miles west of Myerstown. Average of 5 analyses of car load lots made by Midvale Steel and Ordnance Co.
7. Bethlehem Steel Co. property north of Prescott. Average of 59 diamond drill hole samples.
8. Quarry of Cornwall Furnace Co., Lebanon. General quarry sample.
9. Quarry of Cornwall Iron Co., South Lebanon.
10. Property of Anthracite Furnace Co., ½ mile northwest of Cornwall. Average of 4 prospect samples.
11. Drill samples from south side of west end of mine at Cornwall, Sept. 29, 1915.
12. 4 samples of limestone from south side of Middle Hill, Cornwall mine, taken at intervals of 25 feet, Jan. 24, 1919.
13. Reinhard quarry, southwest part of Lebanon. Average quarry sample.
14. Lineweaver quarry, West Lebanon. Average of 21 samples.
15. Stanley quarry, 1½ miles west of Lebanon. General quarry sample.
16. Kreidler quarry, Cleona. General quarry sample.
17. Imboden quarry, ½ mile southwest of Cleona. General quarry sample.
18. Annville Lime Co., (Deitzler) quarry, East Annville. General quarry sample.
19. Sheffy and Mark quarry, East Annville. General quarry sample.
20. Smith quarry, North Annville. General quarry sample.
21. Batdorf and Forney quarry, northwest Annville. General quarry sample.
22. Funk quarry, northwest Annville. General quarry sample.
23. Millard quarries, Annville. a. Average of 3 cars shipped to Thomas Iron Co. during 1929. b. Average of 8 cars shipped to Steelton in 1917. Analyses 1, 3–5, 7–8, 10–22 made by Bethlehem Steel Company.

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LEHIGH COUNTY

Lehigh County is well provided with limestones belonging to the Cambrian and Ordovician systems. The limestone strata aggregate about 4,000 feet in thickness. They are fairly well distributed in that all except the five most northerly townships contain limestones and a few of the central townships have no other rock exposed.

Nearly all the limestones lie within the Great Valley, which cuts across the county and contains most of the towns—Allentown, Catasauqua, West Bethlehem, Fountain Hill, Coplay, Cementon, Egypt, Ormrod, Foglesville, Alburtis, Macungie, and Emaus. Saucon Valley, part of which lies within Lehigh County, is floored with limestones. This is an offshot from the Great Valley. Limestones are exposed also along Hosensack Creek in Lower Milford Township.

*Table of limestones of Lehigh County**

	Feet
Ordovician	
Martinsburg shales and slates overlying the limestones	
Jacksonburg low-magnesian argillaceous limestones used in Portland cement manufacture	600±
Canadian	
Beekmantown limestone composed of alternating high and low magnesian beds	1000±
Conococheague (Allentown) dolomitic limestone	1500±
Cambrian	
Tomstown dolomitic limestone	1000±
Hardyston sandstone and quartzite underlying the limestones	

These limestone formations have been described under both Berks and Northampton counties where additional information concerning them is given.

CAMBRO-ORDOVICIAN LIMESTONES

Tomstown limestones. The Tomstown group contains the oldest limestones of the county. In general they are present only along the southern margin of the limestone valley where they overlie the Hardyston sandstones. Due to complex folding and faulting the normal distribution is not always encountered. The position of the outcropping Tomstown strata near the base of the mountains bounding the Great Valley on the south is not favorable for exposures as the talus from the mountain slopes conceals the edges of these strata. The Tomstown limestones consist of massive, hard, dolomitic and siliceous limestones which are interbedded with shaly layers containing practically no calcium carbonate. No fossils have thus far been found in these strata in this region. The Tomstown limestones have been utilized for blast furnace flux and for crushed stone.

Conococheague (Allentown) limestone. Overlying the Tomstown and at places differentiated from it with difficulty is the Conococheague formation, which has also received the local name of "Allentown." This is the most widespread formation of the county and occupies most

* This column is arranged according to the classification of the Pennsylvania Survey. The author prefers the U. S. Geological Survey classification which does not recognize the Canadian system and places the Ordovician-Cambrian contact at the base of the Beekmantown.

of the southern half of the limestone valley. It consists of thick to thin magnesian limestones, in which alternating beds differ greatly in their content of magnesia and silica. On a weathered surface exposing different beds this variation in the amount of magnesia results in the formation of a banded structure that can be readily distinguished at a considerable distance. Those beds with the greater amount of magnesia become much whiter than those with small per-

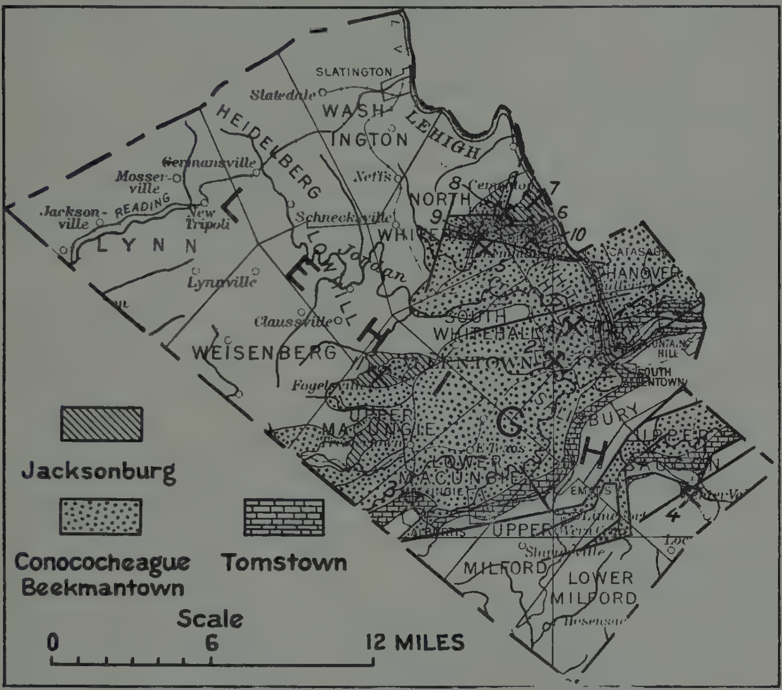

Fig. 23. Limestone areas in Lehigh County.

1. Allen Quarries Co. 2. C. H. Ziegenfuss Co. 3. Alburtis Stone and Sand Co. 4. Frank A. Kuntz. 5. Lehigh Stone Co. 6. Coplay Cement Mfg. Co. 7. Whitehall Cement Mfg. Co. 8. Giant Portland Cement Co. 9. Lehigh Portland Cement Co. 10. Lehigh Portland Cement Co. 11. Lehigh Portland Cement Co.

centages. The presence of occasional layers of *Cryptozoon proliferum*, a form of marine calcareous algae, also serves as criteria for the recognition of the Conococheague formation. These limestones have been quarried in many places for burning to lime, for furnace flux, for building stone and for crushed stone.

Beckmantown limestone. The Beekmantown limestones generally occupy the greater portion of the northern half of the limestone valley. They consist of interbedded low and high magnesian limestones. Some of the beds are sufficiently low in magnesia to be used in Portland cement manufacture, although the interbedded high magnesian stone renders it difficult to avoid a mixture. There are some molluscan fossil remains in the Beekmantown, but they are plentiful in only a few places. These limestones have been used mainly for lime burning, for flux, for crushed stone, and for building purposes and to a minor extent for cement manufacture.

Jacksonburg limestone. The most impure limestones of the county and yet the most valuable constitute the Jacksonburg formation. The Jacksonburg strata in this region consist of a basal member of crystalline high-grade limestone designated "cement limestone," and an upper argillaceous limestone member that comprises most of the formation and is called "cement rock." In some places the two are sufficiently distinct to permit separate mapping but elsewhere they grade into each other and everywhere occasional layers of the basal type are interbedded within the more argillaceous upper member.

In most places in the region, the northern boundary of the cement rock can be accurately determined by an abrupt change in topography, the line of contact being at the base of the steep slopes which mark the southern margin of the slate belt. This change in slope is due to the relative ease with which the cement rock is removed by weathering, mainly solution, in comparison with the much less soluble slate.

In several places the southern boundary of the cement rock belt is also marked by a change in slope. The underlying limestone is more soluble than cement rock, and produces more nearly level land.

The typical cement limestone of the region is a light to dark gray, coarsely crystalline limestone which, when freshly broken, shows lustrous surfaces of dark calcite. Less commonly it is a dark-colored limestone closely resembling in appearance the underlying dolomitic limestones. It is usually massively bedded.

Normally the cement limestone runs high in $CaCO_3$, and low in $MgCO_3$, but it varies greatly in composition. In some quarries considerable rock is obtained in which analyses show from 90 to 95 per cent $CaCO_3$. Also some quarries have a few beds that contain as much as 12 per cent $MgCO_3$, so much that the rock must be sorted out and discarded.

The cement limestone contains numerous fossil remains, most of which, however, are fragmentary and scarcely determinable. They are seldom apparent except on the weathered surfaces of the rocks. They are of the same kinds as those contained in the limestone layers interbedded with the argillaceous cement rock. Fragments of small crinoid stems are most abundant but locally bryozoans are very common. The bryozoans belong to several different kinds, of which the branching and the beadlike colonies are most abundant. Poorly-preserved brachiopods are also found occasionally.

The massive character of the cement limestone beds has prevented them from crumpling, but steeply dipping and overturned folds are present. In the quarry of the Coplay Cement Manufacturing Company on the west bank of Lehigh River an overturned synclinal fold is shown in the south side of the quarry. The syncline is overturned to the north so that the cement limestone both overlies and underlies a mass of "cement rock" with all the beds dipping to the southeast.

Elsewhere in the region the cement limestone normally dips gently to the north or northwest at low angles and disappears beneath the cement rock. This cement limestone is of variable thickness, ranging from 100 to almost 200 feet.

The cement limestone grades into the overlying argillaceous limestone or cement rock by an intermediate band of interbedded, relatively pure limestone and impure argillaceous limestone strata. For that reason the two kinds of rock, although lithologically dissimilar, are regarded as constituting a single geologic formation.

At the base the cement limestone is in contact with the Beekmantown magnesian limestones. In this region the two formations are approximately conformable, although to the eastward in New Jersey a marked erosional unconformity is shown in many places.

Glacial clay of variable thickness, with included cobbles and boulders, rests upon the cement limestone. The glacial cover interferes with the de ermination of the position of the formation boundaries.

The cement rock is an argillaceous limestone intermediate both in composition and stratigraphic position between pure limestone and shale or slate. In color it suggests the overlying slates and in many places it shows marked slaty cleavage. A freshly broken piece is bluish-black in color and shows glistening particles of sericite too fine to be individually distinguishable except as light is reflected by them. The unaltered rock breaks partially along cleavage planes and partially along bedding planes, producing hackly or in some cases conchoidal surfaces that are unlike those of either the pure limestones beneath or the slates above. As the rock weathers, however, it separates into small cleavage fragments so similar to those resulting from the decomposition and disintegration of slate that it is difficult to distinguish between a slate soil and a cement rock soil. Both are filled with thin rock fragments of a light yellowish-gray color varying in size up to 1 inch in length.

In almost every quarry the cement rock shows the effect of great compression by which it has been shattered, permitting water carrying mineral matter in solution to precipitate quartz and calcite in the open fissures and irregular cavities. In places the vein matter is pure white calcite, in other places white granular quartz, but more commonly a mixture of the two. The white veins contrasting with the black rock are very prominent in the working faces of most quarries. The veins are roughly parallel and tend to follow bedding planes, although they break across the beds in many places. Smooth slickensided surfaces coated with a soft black carbonaceous substance resembling graphite are very common on the vein walls.

Small cubes of pyrite are frequently noticed near the veins and occasionally in rock where the vein material is absent. Purple and green fluorite have also been found in a few localities as vein material.

The chemical composition of the cement rock changes from bed to bed or even in the same bed within a single quarry opening. In some quarries the average rock contains almost exactly the right proportion of the various materials required for the best grade of Portland cement. In most quarries the rock varies so that tracks must be run to several parts and the requisite mixture obtained by the proper combination of the various kinds of rock. In other quarries, however, the average rock runs too low in $CaCO_3$ so that it is always necessary to add some high grade limestone. Some of the plants are fortunate enough to have quarries in the underlying cement limestone while others must bring limestone from a distance. Much limestone from Annville, Lebanon County, Pa., is used in the Lehigh district.

In many quarries it is difficult to determine the bedding planes unless an interbedded pure limestone stratum can be found. Where these are absent the quartz and calcite veins, which, in general, are present along the bedding planes, are useful in determining the structure. Almost invariably, the cement rock strata are greatly crumpled

and yet have low angles of dip. The normal direction of dip is toward the northwest beneath the Martinsburg slates, which constitute the slate hills, but in many quarries some beds can be found dipping in other directions.

When the region was subjected to the great dynamic forces which formed the Appalachian folds the cement rock strata were so weak that they yielded by minor folding and faulting, resulting in local thickening of the different layers, but without producing high angles of dip. In very few places can one find the cement rock dipping more than 45° and usually the dip is much less, while in the adjoining limestone belt vertical or even overturned beds are not uncommon.

The crumpled character of the cement rock, the absence of any beds sufficiently distinct to be recognized in different openings, and the lack of any continuous or approximately continuous section across the belt normal to the strike render the exact determination of the thickness impossible. The local thickening of the beds due to compression also needs to be taken into account in any estimates of thickness.

UTILIZATION OF LEHIGH COUNTY LIMESTONES

As mentioned above, the various limestones of Lehigh County have been utilized for different purposes. All except the Jacksonburg have furnished satisfactory stone for lime burning, for flux, for building stone, and for crushed stone. The Jacksonburg and some of the Beekmantown have been used for cement. At the present time cement manufacture is the most important limestone industry, and next to that is crushed stone which is needed in large quantities for highway construction and for concrete structures.

History of the cement industry in the Lehigh Valley. The most valuable economic mineral product of the region is the cement rock of the Jacksonburg formation. Nowhere else in the entire country is there known to be another occurrence of argillaceous low-magnesian limestone equally well adapted to the manufacture of Portland cement, and so favorably situated. The Lehigh district, as it is called, embracing the cement plants of Northampton, Lehigh, and Berks counties and three plants in New Jersey, produces about 25 per cent of all the Portland cement of the United States, a pre-eminent position which it has held from the beginning of the industry in this country. With the exception of some high calcium limestones that are brought into the district from other regions by those companies whose local quarries furnish stone deficient in the calcium content, all of the required stone comes from the Jacksonburg formation. Twelve cement companies are operating in the Pennsylvania portion of the district, several of which have two or more quarries and plants.

As in other regions, the manufacture of natural hydraulic cement preceded that of Portland cement. In New York the construction of the Erie Canal in 1818-19 led to the discovery of natural hydraulic cement; in this State the digging of the canal of the Lehigh Coal & Navigation Company accomplished the same object. Rock suitable for hydraulic cement was found just above Lehigh Gap, where Palmerton is now located, and also at Siegfried's Bridge (now Siegfried). The rock at the former locality seemed to be preferable and a cement mill was built at Lehigh Gap under the direction of the company's engineers. This was operated by Samuel Glace from 1826-1830 and

furnished material for many of the canal locks. When the best cement rock was exhausted near Lehigh Gap, for a time material was quarried about 6 miles east of the Gap and hauled to the plant. However, in 1830 it was decided to abandon the mill and erect a new one at Siegfried's Bridge where suitable rock was known to exist. In a small pamphlet by William H. Glace entitled "A Narrative of Hydraulic Cement Mined in the Lehigh Valley" the following description is given:

"Capt. Theodore H. Howell, residing at Siegfrieds, informed me that when he came there in 1837 there were four kilns erected and in operation. They were known as draw kilns, fire being placed in the eye at the bottom of the kilns, drawn at the bottom and hoisted up an incline plane or tramway and emptied into a hopper, where the stone was crushed by machinery shaped like a corn crusher, then dropped down and ground by burr millstones, then placed in boxes or trays with handles, then transported in scows to points on canal where needed. At that time the capacity of this plant was ten barrels per day."

Natural hydraulic cement continued to be manufactured in the region as shown by the following quotation from "History of the Lehigh Valley" by M. S. Henry, published in 1860 (7, p. 302).

"On the eastern side of the river, directly opposite the village (Whitehall, now Cementon), are the extensive Hydraulic Cement Works of E. Eckert and Co. These works have been in successful operation for a number of years, and the cement (which is mined in the neighborhood) is said to be equal in every respect to the celebrated Rosendale cement."

As early as 1867 David O. Saylor, who was at the head of a natural hydraulic cement company located at Coplay and called the Coplay Cement Company, began experimentation to try to improve the quality of their cement. In the preceding year the first Portland cement was brought to this country from England where it had been manufactured for several years, and this fact seemed to act as a stimulus to cement manufacturers in this country. By selecting the stone carefully Saylor finally succeeded about 1872 in making Portland cement which was exhibited at the Centennial Exposition where it received a "Certificate of Award."

The Coplay Cement Company (now the Coplay Cement Manufacturing Company) continued to make Portland cement, steadily improving its quality, while other plants were soon started in the same vicinity. For some years many difficulties were encountered while the importations of Portland cement from England were gradually increasing. In time, however, the Portland cement of the Lehigh district acquired the reputation, which it still holds, as the equal of any Portland cement made and cement importations practically ceased. The situation in 1878 is described by Prime (4, pp. 164-165) in his report on the geology of Lehigh and Northampton counties.

"Two companies, as mentioned in Report DD, have tried to utilize the hydraulic properties of this limestone in Northampton County, but neither of them have done much of anything in the last four or five years, and every time the quarries have been visited by members of the present geological survey they have been found standing unworked. These companies are 'The Old Lehigh Cement Works,' and 'The Allen Cement Company.'

"It must not be supposed that because these companies have been apparently unsuccessful, that there is no future in the business of manufacturing hydraulic cement in this part of the State; on the contrary the success of the Coplay Cement Company shows what perseverance under difficulties can and does accomplish. Of course, the composition of some of the cement-stone beds is far more favorable to the manufacture of cement than that of others, but all may be more or less profitably utilized for careful intermixture. There is no reason why the manufacture of hydraulic and Portland cements should not be slowly and surely extended, not only rendering this portion of the State free from foreign competitors, but actually rivaling these in many of the western markets on account of the excellence of the product and the cheapness of freights."

For many years both natural and Portland cements were made in the district, in some cases even by the same company, but at present little natural cement is produced. Only a few years ago a natural cement company located at Egypt ceased operating and dismantled its kilns

The Lehigh district enjoyed almost a monopoly in the manufacture of Portland cement until it was discovered that an equally good product could be made from a variety of materials. Lehigh cement was shipped all over the country and much of it exported. While no other cement region occupies so favorable a position with reference to accessibility to good cement rock and fuel and proximity to great industrial centers, yet on account of freight charges the market for the cement of the Lehigh district is year by year restricted by the erection of cement plants in other sections of the country. Fortunately, however, the demand for Portland cement has kept pace with the growth of cement manufacturing plants so that the district continues to prosper regardless of increasing competition.

In this region many improvements have been made since the first successful manufacture of Portland cement. For a time the run of quarry was used, with the result that some companies which owned quarries in which the rock had practically the composition now looked upon as most desirable, were able to produce a better product than other companies with less suitable rock. Also few companies were able to produce a uniform product on account of the variation in composition of the rock even in the same quarry. Now, however, the chemist of each company sees that the proper mixtures are used, and the physical tests also serve as a check, so that the old hit-or-miss method has given place to the exact scientific processes and the variations in the product are very slight.

The change in mechanical processes of manufacture have been equally great and each year mechanical modifications are introduced which tend to increase output and lower cost of production. The greatest improvements have been in the character of the kilns by which the old upright kiln has given place to the modern rotary kiln now universally used throughout the region.

QUARRY DESCRIPTIONS

In most of the counties, it has seemed best to describe the active or recently worked quarries by geographic districts inasmuch as the same quarries yield products used for widely different purposes. In Lehigh

County it seems preferable to describe the operations according to their products, since the individual quarries are worked almost solely for a single product and a single use. At present, Portland cement and crushed stone are the limestone products of Lehigh County. The old quarries once worked for lime to supply the farmers with this valuable fertilizer are now abandoned and the kilns are falling into ruins. The building of stone houses from local limestones is almost a thing of the past and this is to be regretted as many of the old stone houses constructed 50 to 100 years ago or even earlier are most attractive. The demand for local stone for blast furnace flux has disappeared with the abandonment of the old iron furnaces that once were active throughout the county. Offsetting these changes, however, has been the increase in the use of crushed stone and Portland cement so that the value of the limestone products of the county is far in excess of what it was at an earlier day before the development of these two phases of the limestone industry. The descriptions of operations are therefore confined to cement and crushed stone quarries and the numerous abandoned quarries will be ignored.

Crushed stone. The largest amount of crushed stone in Lehigh County has been produced in the vicinity of Allentown. Along the Central Railroad of New Jersey on the east side of Lehigh River, a large amount of stone has been quarried in recent years for crushed stone. Previously these quarries furnished stone for burning lime. These quarries are now closed and may not be re-opened because of their proximity to the railroad tracks. Several similar openings in the south part of Allentown that were once worked are now abandoned.

On North Seventh Street in the north part of Allentown the Allen Quarries Co. is operating a quarry in dolomitic limestone of the Conococheague (Allentown) formation for crushed stone. A small amount of fluxing stone is sold to foundries. The quarry is about 300 feet long and 250 feet wide with a working face about 60 feet in height. The beds strike of N.84°W. and dip 45° SW. There are several different kinds of stone in the quarry. The most abundant is a dark blue compact dolomite. There are a few shaly beds. Fine oolite, edgewise conglomerate, and black to almost white flint nodules are common. The stone has been badly shattered in places and contains many veins of calcite and quartz. A few layers show grains and even small rounded pebbles of quartz. The stone is hard and well adapted for use in concrete. An analysis made in the laboratory of the Lehigh Portland Cement Co. showed 54.42 per cent $CaCO_3$, 41.03 per cent $MgCO_3$, and 2.02 per cent SiO_2. The daily output is about 300 tons.

The C. H. Ziegenfuss Co. has for many years been working a quarry in southwest Allentown at 20th and Fairview Streets. The stone is a part of the Conococheague (Allentown) formation and is similar to the dolomite worked by the Allen Quarries Co. From this quarry at one time stone was obtained for flux and for lime burning, but at present only crushed stone is being produced. The annual capacity is given as 125,000 tons.

The Alburtis Stone and Sand Co. is working a quarry along a branch of the Reading Railroad about a mile north of Alburtis. The quarry is a new one and as yet small. The face is about 40 feet high in one place. The stone is dolomitic and belongs to the Conococheague (Allentown) formation and contains layers of *Cryptozoon proliferum*. The beds

are fairly massive, although somewhat shattered. They strike N.59°W. and dip 10°NE. The plant is well equipped with crushers and screens. An analysis made in the laboratory of the Valley Forge Cement Co. is as follows: $CaCO_3$, 54.42; $MgCO_3$, 42.33; $Fe_2O_3+Al_2O_3$, 0.90; SiO_2, 2.50.

About three-fourths mile northeast is an old quarry belonging to John A. Walbert recently worked for highway stone. Previously for about 30 years this quarry was worked for flux for the Lockridge furnace of the Thomas Iron Co. The stone is a dolomite of the Conococheague (Allentown) formation. The quarry face is about 500 feet long and 70 feet high.

Frank A. Kuntz has a small crushed stone quarry about half a mile south of Center Valley. The stone is a dolomite containing over 40 per cent $MgCO_3$. He lists his annual output as follows: 3000 tons crushed stone, 1000 tons limestone sand, 100 tons pulverized limestone, and 10 tons poultry grits.

The Lehigh Stone Co. is working a quarry for crushed stone about half a mile south of Ormrod. It is an extension of the Lobach quarry, which was worked for a number of years to obtain high grade limestone for some of the cement plants. At one time the Giant Portland Cement Co. mined limestone here. The present company is working this band of good stone which varies from 35 to 150 feet in width and selling it to the Lehigh Portland Cement Co. It contains from 85 to 94 per cent $CaCO_3$. The output of this grade of stone is said to amount to 150 tons per day. Overlying the high-calcium stone there are dark colored, extremely hard, mainly thin-bedded dolomites. The stone is said to contain more than 40 per cent $MgCO_3$. The main quarry has been developed in this type of stone. The present opening is about 400 feet long, with a working face 300 feet wide and 70 feet in height. The lower beds exposed have been greatly folded but the upper ones exposed are fairly regular with a strike of N.57°E. and a dip of 19°SE. The capacity of the plant is about 1000 tons of crushed stone daily.

Cement plants. Four different Portland cement companies have 9 plants in Lehigh County. All are working the argillaceous limestone of the Jacksonburg formation described in an earlier part of this chapter. A general description of the physical and chemical characteristics of the stone used is equally applicable to all the quarries. In detail, there are some important differences in that the percentages of $CaCO_3$ and $MgCO_3$ may vary a few points and thus render the stone highly acceptable or otherwise. In general the Jacksonburg limestone of Lehigh County is deficient in $CaCO_3$, thus necessitating the purchase of high-calcium stone, most of which comes from the Lebanon Valley.

The oldest cement operation in the State is that of the Coplay Cement Manufacturing Co. located about half a mile northwest of Coplay with the present quarry about half a mile farther west. The first plant and quarry were situated close to Lehigh River just above Coplay but these have long since been abandoned although the old upright kilns are still standing. The present quarry is about 180 feet deep. It contains stone of different composition. The company has done a great deal of prospecting by deep drilling and has discovered stone of higher composition than that exposed in the quarry. One of the holes put down in the bottom of the quarry was sunk to a depth of 550 feet or a total depth of 730 feet from the original surface. The

Jacksonburg limestone was still present at that depth. Due to the fairly complicated folds and faults in the quarry, one can not be sure that the Jacksonburg formation at that place is 730 feet thick, although it may be. The company uses the dry process of cement manufacture. The plant has 11 kilns and has an annual output of 2,400,000 barrels.

The first operation of the Universal Atlas Portland Cement Co. was located just north of the old quarry of the Coplay Cement Manufacturing Co. but this mill and quarry were abandoned many years ago and the operations continued on the east side of Lehigh River in Northampton County.

The Whitehall Cement Manufacturing Co.'s plant and quarry are at Cementon. The quarry shows the same variations in chemical composition of the argillaceous cement rock that is characteristic of the formation. Certain ledges are deficient in $CaCO_3$ and others contain more than is needed for the proper mix. As the result of extensive prospecting by means of drilling the areas of high and low calcium carbonate stone have been fairly well determined so that the quarrying can be continued to best advantage. The beds have been considerably crumpled but in general they dip to the north or northwest at angles of 10 to 18 degrees. The quarry face is about 150 feet in height. A drill hole 245 feet deep in the bottom of the quarry failed to reach the underlying dolomite, thus indicating a thickness of at least 400 feet of the Jacksonburg argillaceous limestones at this point. The mill is equipped with 5 kilns and has an annual output of 2,200,000 barrels. The dry process is used.

Along Coplay Creek just southeast of Egypt there is an old cement rock quarry and a number of kilns where natural cement was long made. At the present time no one would consider the manufacture of natural cement profitable in this district.

The Giant Portland Cement Co. has 2 mills and 2 quarries in the Egypt region. The Central mill and quarry are located about three-fourths mile southeast of Egypt. The quarry was abandoned several years ago and stone brought from the Reliance quarry, but in recent years the mill also has been shut down. The Reliance mill and quarry, where work is now concentrated, are located about three-fourths mile southwest of Egypt. The company has the normal cement rock in the Reliance quarry, black argillaceous limestone somewhat deficient in $CaCO_3$ for the proper mix. In parts of the quarry the stone is better than the average and the quarry is being advanced in those directions. The quarry is large. A great deal of prospect drilling has been done in the floor of the quarry and in undeveloped farms which the company owns. The dry process is used. There are 14 kilns and the annual output is 2,000,000 barrels.

The Lehigh Portland Cement Co. has five mills in Lehigh County. Mills A, D, and F are at Ormrod, B is at West Coplay, and H at Fogelsville. All of them are using the Jacksonburg argillaceous limestones. Several different quarries have been operated in the Ormrod and West Coplay localities, all of which show the variations and deficiencies in chemical composition described above. The operation at Fogelsville is more favorably situated in that stone of better grade has been located there.

In a forthcoming geologic report on Lehigh County to be published by this Survey, more details concerning the individual quarries will be given.

Analyses of Cambro-Ordovician limestones

	1	2	3	4	5a	5b	5c	5d
CaO	27.8	----	----	----	18.23	28.33	27.44	28.10
MgO	18.01	----	----	----	19.20	19.79	18.33	19.56
Al_2O_3	----	1.12	1.75	0.65	1.39	1.40	2.31	2.75
Fe_2O_3	----	0.79	0.52	0.66	----	----	----	----
SiO_2	8.97	3.80	3.30	1.20	6.40	3.89	8.91	6.75
$CaCO_3$	----	52.08	51.60	51.73	----	----	----	----
$MgCO_3$	----	41.29	42.60	45.35	----	----	----	----

	6a	6b	6c	7a	7b	8	9	10
$CaCO_3$	53.20	51.36	53.25	51.920	47.890	49.316	83.632	70.750
$MgCO_3$	41.30	39.72	37.10	41.071	39.585	40.463	5.462	15.256
Al_2O_3	1.50	2.68	3.17	----	----	0.70	----	.860
Fe_2O_3	----	0.92	1.11	----	----	----	----	----
SiO_2	2.32	4.70	4.42	5.650	11.260	8.980	7.850	11.070
S	----	0.026	0.026	trace	trace	----	----	----
P	0.010	0.012	.010	.011	.021	.006	.026	.019

	11	12a	12b	13	14	15	16
$CaCO_3$	56.220	51.558	86.036	51.603	48.630	74.05	69.00
$MgCO_3$	31.201	35.216	4.594	32.917	40.410	4.09	5.70
Al_2O_3	.300	.140	.065	----	----	5.19	5.40
Fe_2O_3	----	----	----	----	----	1.87	
SiO_2	10.980	10.750	8.400	13.490	9.240	12.66	19.82
S	----	----	----	.147	.005	----	----
P	005	.018	.016	.012	.012	----	----

1. Tomstown limestone. Morey farm, ½ mile southwest of Center Valley, Lehigh County. Analysis by Bethlehem Steel Co.

2. Tomstown limestone. Ackers quarry, south of East Allentown and a short distance northeast of bend in Lehigh River, Lehigh County. Analyzed by Bethlehem Steel Co.

3. Tomstown limestone. New Jersey Zinc Co. quarry, along Lehigh River just north of East Allentown, Lehigh Co. Analysis by Bethlehem Steel Co. Material used for flux at Palmerton plant of New Jersey Zinc Co.

4. Allentown limestone. Hardners quarry along Little Lehigh Creek, Allentown, Lehigh County. Analysis by Bethlehem Steel Co.

5. Beekmantown limestone. Outcrops at Ueberroth pit of New Jersey Co.'s zinc mine ½ mile north of Friedensville, Lehigh County. Analyses by Bethlehem Steel Co.

6. Beekmantown limestone. Eberhart's quarry, west side of Lehigh River, opposite Catasauqua, just north of junction of Coplay Creek and Lehigh River, Lehigh County. a. Analysis by the Bethlehem Steel Co.; b and c analyses by the Thomas Iron Co. b represents the average of 183 cars shipped to the Thomas Iron Co. during the first half of 1920 and c the average of 166 cars shipped during the latter half of 1920.

7. Beekmantown limestone. Thomas Iron Co.'s quarry, ¾ mile north-northwest of Alburtis, Lehigh County. a. limestone, hard, compact and of a bluish gray color. b. limestone, compact, highly crystalline, and of a bluish gray color. (Pa. Second Geol. Survey Report M, p. 76)

8. Beekmantown limestone. Mary Kohler quarry, ¾ mile west of Whitehall station, L. V. R. R. Brecciated limestone; various shades of blue and gray. (MM, p. 309)

9. Beekmantown limestone. Ironton Railroad Co.'s quarry, 1 mile southeast of Ironton, Lehigh County. Hard and compact; bluish gray. (MM, p. 310)

10. Beekmantown limestone. Edward Guth quarry. At Guth's Station, 4½ miles west of Catasauqua, Lehigh County. Fine grained; dark blue, with slaty structure. (MM, p. 310)

11. Beekmantown limestone. Thomas Iron Company's quarry, at Guth's Station, Lehigh County. Fine grained, bluish gray; with some quartz. (MM, p. 309)

12. Beekmantown limestone. Eph. Wenner quarries at Jordan Bridge of the Catasauqua and Fogelsville R. R. 4½ miles northwest of Allentown, Lehigh County. Leased by Crane Iron Co. a. "Hard limestone," fine-grained; hard and brittle; spotted with pyrites; bluish gray. b. "Soft limestone." Comparatively soft, fine grained, dark blue, with laminated structure. (MM, p. 309)

13. Beekmantown limestone. Mrs. Kuhn's quarry 1½ miles northeast of Trexlertown, Lehigh County. Limestone, compact, siliceous and of a light bluish-gray color. (M, p. 76)

14. Beekmantown limestone. Frantz quarry, 1½ miles northeast of Trexlertown, Lehigh County. Limestone, hard, siliceous, of a dark blue color. (M, p. 76)

15. Jacksonburg cement rock. Whitehall Cement Company's quarry, Cementon, Lehigh County. Analysis by Whitehall Cement Company.

16. Jacksonburg cement rock. Typical analysis of stone in quarry No. 2, of Coplay Cement Manufacturing Co., Lehigh County. Analysis by the company.

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General

7. History of the Lehigh Valley by M. S. Henry, 436 pp., Easton, 1860.

The limestones of Luzerne County are of little importance and may almost be disregarded entirely. Within the Catskill and Chemung series of rocks some impure limestones have been found but they have never been utilized so far as known. The Tully limestone, lying just above the Hamilton shales, has been noted but it is everywhere extremely impure and worthless as a limestone. The Onondaga limestone may be seen in road and railroad cuts in the vicinity of Beach Haven, but is of no economic importance. It consists of interbedded gray, calcareous shale and light to medium gray limestone.

The only limestones ever used within the county seem to be those belonging to the Coal Measures. C. A. Ashburner made a careful investigation of these limestones and the following paragraphs are abstracted from his report.

"In the Coal Measures of the anthracite region, however, the occurrence of limestone-beds is rare, and the only locality where clearly defined and persistent beds of limestone have been located by the Geological Survey is in the Wyoming valley. These beds are of special interest to geologists and palaeontologists, on account of the number of fossil remains of water shells found in one of the most persistent of the beds, and which I have named the Mill Creek limestone-bed.

"The existence of limestone in the coal measures of the Wyoming valley, particularly in the vicinity of Wilkes Barre, has been recognized for many years. A farmer on the farm of Judge Garrick Mallory is reported to have quarried limestone, over 15 or 20 years ago, from an outcrop on the south side of Mill creek, below the mouth of Laurel run at a locality to be referred to later, and to have gathered loose pieces of stone from the surrounding fields; this limestone was burned in an old kiln in the immediate vicinity for lime, which was used principally as a fertilizer.

"Dr. Charles F. Ingham and Mr. Chris. H. Scharar, prominent and active members of the Wyoming Historical and Geological Society, together with the late Mr. Harrison Wright, secretary of the society, and other members, have made an interesting collection of fossil specimens from an outcrop of one of these Wilkes Barre limestone beds, near the old Hollenback dam across Mill creek, at the head of a supply race of the now abandoned New York and Pennsylvania canal. This limestone outcrop is on the Mill Creek beds." (1, pp. 438-439.)

"The Mill Creek limestone-bed outcrops along the north side of Mill creek, near the breast of the old Hollenback dam, and about midway between the River Street bridge and a bridge of the Lehigh Valley railroad, which crosses the creek immediately at its mouth.

"The limestone is siliceous, ferruginous, and extremely hard, and from 1 foot to 15 inches thick.

"It occurs between the Prospect shaft anticlinal, which runs due west from Prospect Shaft across the Susquehanna river, and the center of the Cemetery basin; the axis of the basin crosses River street about midway between Chestnut and Linden streets.

"The dip of the strata, where the limestone outcrops, is toward the south. All the specimens of fossils obtained from this stratum were very much stained with oxide of iron.

"When the lock of the Mill Creek Slack Water Navigation, on the south side of the creek and immediately opposite this limestone outcrop, was built, about 1865, a number of fossils were obtained from the excavations made in the calcareous black slate at the foot of the lock.

"The Mill Creek limestone outcrops again along the fence of the Hollenback Cemetery, facing the Susquehanna river on the west side of Mill creek, about 65 feet south of the Lehigh Valley railroad track.

"On the road between Kingston and Plymouth, and about half a mile north-east of the Boston breaker, an outcrop of limestone occurs which is 2 feet thick. This outcrop Mr. Scharar (Schaarer) believes to be on the Mill Creek limestone." (1, pp. 443-445.)

"On the south-east bank of the canal, 800 feet south-west of the mouth of Mill creek, and near the line separating the Hollenback and the Public Cemeteries, occurs an outcrop of a siliceous non-fossiliferous limestone much softer than the Mill Creek limestone. This bed I have named the Canal limestone, and it occurs about 30 feet stratigraphically below the Mill Creek bed. The Canal limestone is 2± feet thick." (1, p. 445.)

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LYCOMING COUNTY

The limestones of Lycoming County are almost entirely confined to the proximity of Susquehanna River which follows the strike of the limestones through the southern part of the county which is the most thickly settled section. The easy development of transportation facilities in the Susquehanna valley has been responsible for the establishment of industries and the building of towns and villages. The other portions of the county are mainly underlain by shales and thick sandstones producing a more rugged topography and less fertile soils.

The principal, and almost the only, limestones of Lycoming County belong to the Canadian, Ordovician and Helderberg (including the Tonoloway) series. Others are of distinctly minor importance.

CANADIAN AND ORDOVICIAN LIMESTONES

The limestones of Canadian and Ordovician age are confined to Nippenose and Mosquito valleys. The former is mainly within Lycoming County but extends across into Clinton County, whereas the latter is entirely within the county. Both of them are typical anticlinal valleys and are in line with the much larger Nittany Valley of Centre and Clinton counties. If all the material removed by erosion since the mountain folding took place could be restored, the center of the folds, and consequently the highest elevations, would be found where now the centers of the valleys have developed. The oldest rocks are therefore exposed in the center and from that axis the beds dip outward and successively younger rocks appear as one goes to the margins of the valleys, where the limestones dip beneath the Ordovician shales and they in turn beneath the hard resistant sandstones that form the high bounding valley walls. The only easy access to these valleys is along the streams that drain them and that have cut deep narrow gaps in the enclosing barriers. No railroads enter Nippenose or Mosquito valley. So far as known, all of the limestones exposed in the valleys belong to the Canadian and Ordovician but the Cambrian dolomitic limestones may lie beneath.

Near the margins of these valleys the limestones are fairly pure. The Bellefonte ledge appears to be present but in greatly reduced thickness as compared with its occurrence in Centre County. The rocks nearer the center of the valleys are mainly high in magnesian content and hence well adapted for highway and concrete construction purposes. There is an abundance of stone of this character. Also there is a large supply of stone that would be suitable for agricultural lime or pulverized agricultural limestone, although it is doubtful whether the local demand is such as to make it commercially profitable to produce either of these products except on a small scale.

DESCRIPTION BY DISTRICTS

Mosquito Valley. Mosquito Valley lies about 3 miles southwest of Williamsport. It is a symmetrical, oval-shaped valley, enclosed by mountains rising about 800 to 900 feet above the floor of the valley. The limestones are exposed over an area about 2 miles long and half a mile wide. They have been quarried in a few places for local use.

In the report on Lycoming and Sullivan counties of the Second Geological Survey of Pennsylvania (2, pp. 77-78) there is the following description of a black marble quarry formerly worked.

"Near the east end of Mosquito Valley, a marble quarry has been opened. It yielded the fossil named *Calymene senaria.*

"The rock is a black limestone; quarries out in large blocks and takes a handsome polish. It is reported however not to stand exposure, but splinters up on weathering. This would render it useless for any outside work, but might still leave it of value for inside decorations.

"When the quarry was examined (in 1875), the works were in operation; they had one gangsaw, capacity 100 tiles per diem; these tiles usually 12″ x 12″ x 1″; the tiles going to Philadelphia and the stone to Philadelphia or Washington.

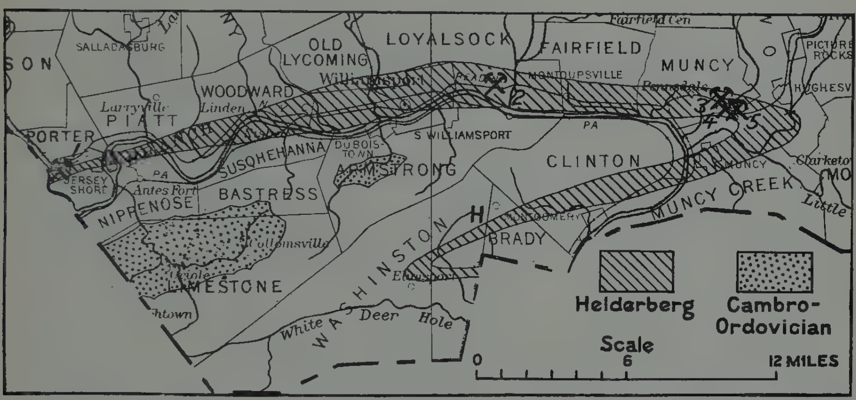

Fig. 24. Limestone areas in Lycoming County.

1. Pine Creek Lime and Stone Co.
2. West Branch Lime Co.
3. Henry Kilgus
4. Reeder Lime and Stone Co.
5. Lime Bluff Co.

"All of the marble is dark colored, very slightly fossiliferous, regular in bedding and works easily.

	Ft.	*In.*
Surface bench, in small layers, 1″ to 2″ and up to 1′, ...	10	0
Middle bench, in regular layers, from 2′ to 1′ thick	20	0
Lower bench, massive and hard, but no stone from it yet shipped	6	
Total	36	0

"The dip of these rocks is north 4°; the quarry is about on the crest of the anticlinal, and the dip is simply the dying gently of that anticlinal northeastward.

"Of the above 36 feet of black marble much proved shelly on quarrying, and split into pieces; a considerable part, however, coming out in handsome blocks.

"It is reported to burn to an excellent white lime.

"There are some curious soft and rotten layers of stone lying between the firm and hard marble layers thus:

	Ft.
Hard marble	1
Soft decomposed marble	......
Hard marble	1½

the underlying and overlying hard rocks being perfect and unbroken so far as traced."

The pits indicate that a considerable quantity of stone was taken from the locality. It is said that the stone acquired a bad reputation because of the ease with which it disintegrated on exposure to the air, a reputation that it probably deserves as shown by the pieces of rotten stone now lying about the quarry openings. For interior use, however, it appears to be satisfactory. A table top and a carved pedestal seen in a home in Duboistown and said to be about 50 years old were in good condition and very attractive. The openings were on the steep slope of a hill. It appears that considerable difficulty was experienced in locating satisfactory stone without removing an unusually large amount of worthless material.

Nippenose Valley. Nippenose Valley lying about 5 miles south of Jersey Shore, is 10 to 11 miles long, and 3 to 3½ miles wide. It is entirely surrounded by a mountainous wall of sandstone through which the stream that carries its drainage waters into Susquehanna River has cut a gap.

The soil of the valley, although comparatively thin in most places, is fertile and there are many fine farms in the region. The limestones are honey-combed with subterranean caverns and most of the drainage is by underground channels. The stream that carries the water out of the valley emerges only a short distance from the gap. Sink holes are numerous throughout the valley.

In a number of places the limestones have been quarried for agricultural lime and for highway construction. A black impure shaly limestone grading into black shale has been quarried as a mineral filler and pigment near Rauchtown in Lycoming County. It is the same rock described under Clinton County. It is ground for shipment at a mill located within the gap. This rock seems to belong to the same horizon as the black marble of Mosquito Valley, described above. In both cases the black stone is close to the contact with the overlying Ordovician black shales.

The most extensive quarrying operation in recent years has been developed near the gap in Bald Eagle Mountain made by Nippenose Creek. The quarry face is about 75 feet high and 400 feet long. At the extreme western end the rock is dark and somewhat argillaceous but more massive, harder and purer in the eastern portion. Several small caves have been discovered in the process of quarrying and a fairly large underground stream located. The stone has been burned for agricultural lime for local use. A small quarry on the Collomsville road has been worked for road metal. The rock breaks with a conchoidal fracture. At Collomsville a small quarry is worked by Charles Laubach to supply stone for 2 lime kilns. The rock is gnarly in character. Near Oriole, Walter Eiswort has a quarry and 2 lime kilns. He burns the stone for agricultural lime.

In the report of the First Geological Survey of the State (1, p. 490) it is stated that "at Bixler's tavern in the east end of the valley there is a so-called 'marble quarry,' which affords a hard solid dark-blue limestone, variegated by thin veins and specks of yellow and sometimes, white, spar, and susceptible of a good polish. Its dip is 15°S. 20°E. The same rock might be traced through the valley near its center line."

HELDERBERG LIMESTONES

The Helderberg series of limestones crops out in an almost east-west belt through Lycoming County, in the Susquehanna Valley from Jersey Shore to within two miles of Muncy and is approximately two miles wide. The belt includes the large quarries at Jersey Shore, Montoursville, and Hughesville. At the latter place the belt swings southwestward and crosses the Susquehanna at Muncy. It has a southwest trend to Elimsport and at that town makes a sharp turn to the east. It is on this backward swing that it passes through the White Deer Valley into Union County.

Four areas in this county visited and described are Jersey Shore, Montoursville, Hughesville, and White Deer Valley.

DESCRIPTION BY DISTRICTS

Jersey Shore Area. The Helderberg limestones in the Jersey Shore area are best exposed in two hills lying east of Pine Creek and west and southwest of the borough of Jersey Shore. At one time it was planned to utilize these limestones for Portland cement and the erection of a plant was contemplated. The project fell through for various reasons. In general, the results obtained in the exploration investigations seemed to be favorable although the variability in composition of the strata is such that it would always require a great deal of care to maintain a uniform mixture. The presence of chert in certain layers in the form of nodules is also undesirable.

There are three quarries in the Jersey Shore locality, one of which was being operated in 1929 by the Pine Creek Lime and Stone Co.

The Jersey Shore Borough quarry is being worked intermittently and in it both flanks of a syncline can be seen. It is somewhat less than a quarter of a mile east of the trolley bridge over Pine Creek. The northern flank of the syncline so well exposed in this quarry dips 15°SE, and the southern limb 50°NW. Along the axis there has been considerable shattering and the material is not good for road use. The upper layers are shaly, weather to a buff yellow, and are brittle. The lower beds are massive and contain some chert. Few fossils were found and the lithological character, together with the finding of chert, indicates that the formation is of Keyser age.

The Pine Creek Lime and Stone Co. has two quarries about one mile southwest of Jersey Shore. The company was operating the larger and more westerly one in 1929 for highway crushed stone and the other one for lime. The limestones are mainly blue and rather impure, much shattered and the cracks filled with small calcite veins. The beds are fairly thin, seldom more than 8 inches. There are some interbedded shale layers and a small amount of sandstone. In one of the calcite veins a small amount of petroleum, perhaps half a teaspoonful, was found. It was clear and burned readily. The workmen report that occurrences of this kind are not rare. The cavity in which the oil was found was lined with calcite crystals. Some cubes of fluorite have also been observed here. Numerous brachiopods and one large pelecypod were noted. The rock has been accepted for road construction by the State Highway Department.

The smaller quarry whence stone for burning is obtained contains more pure limestone. There are some shaly bands and considerable

surficial clay. The rock has been greatly squeezed and crushed and calcite veins are numerous. There are many coral and bryozoan fossils in the exposed beds.

Montoursville Area. On the north side of the road between Williamsport and Montoursville several quarries have been opened to obtain stone for roads, for lime, and for building purposes.

Bower Brothers quarry, midway between Williamsport and Montoursville, has been worked intermittently for more than 50 years. The quarry is about 400 feet long and 100 feet wide with a face about 20 feet high. The strata dip to the north at angles of 10° to 15°. Shaly stone that is not suitable for lime is used for walls and rough construction. The good stone is mottled, strikingly so when weathered. There are two kilns. The product is called the Blue Stone Lump Lime and used for agricultural purposes and for plastering. Many cracks and solution pockets filled with clay and occasional alluvial boulders up to two feet in diameter have been encountered in the quarry.

Nearer Montoursville there are two adjoining quarries in the Helderberg limestone. One of them belonging to Loyalsock Township has been worked for road metal. The strata dip 5° to 10°N, except at the northeast end of the quarry where they are almost vertical and badly shattered. The other quarry is operated by the West Branch Lime Co. The beds here dip 18° to 20°N. in the major part of the quarry, but in the east end the axis of an anticline is shown with the beds dipping south. The strike is approximately parallel to the highway. The quarry is about 300 feet long, 100 feet wide, and the working face up to 50 feet high.

Section in quarry of West Branch Lime Co., Montoursville

	Feet
Light blue limestone, weathering white	6
Thin-bedded, shaly limestone	6
Light blue limestone breaking into cubic blocks	20
Hard, buff-colored limestone, many fossils (analysis No. 1)	4 to 4½
Thin-bedded, shaly limestone (analysis No. 2)	8
Dark blue, rather massive limestone, glassy fracture (analysis No. 3)	5
Dark dove-colored limestone fairly thin-bedded (analysis No. 4)	6

Analyses of lower beds of above section

	1	*2*	*3*	*4*	*Composite sample of quarry*
$CaCO_3$	91.81	79.45	87.85	85.54	89.74
$MgCO_3$	3.78	6.56	3.96	3.17	2.42
$Al_2O_3 + Fe_2O_3$	.59	1.70	1.09	1.49	1.45
SiO_2	3.82	12.06	6.96	9.63	6.48
SO_3	trace	.23	.14	.17	

The first four analyses were made by G. V. Brown, Bucknell University and the last one was made at Pennsylvania State College.

Fossils and sun cracks are common in the more shaly layers. Near the east end of the quarry in 1929 a calcite vein from half an inch to 4 inches thick was exposed in which there was considerable galena and a little sphalerite.

The quarry face is being worked northward and is also being extended eastward along the strike. At one time the quarry was worked for building stone but more recently only for stone for burning lime. There are 7 kilns but only 5 were in use when the plant was visited. The lime is used mainly for agricultural purposes, although some is sold for mortar. About one-fourth is hydrated. The capacity production is about 6,000 tons annually but in recent years only about one-third that amount has been produced.

About 3 miles east of Montoursville there are two abandoned quarries where a little limestone has been obtained.

Hughesville Area. A short distance west of Hughesville there is a ridge of Helderberg limestone that extends for a little over a mile. In it much stone has long been quarried for lime burning, for crushed stone, and to a lesser degree for building stone. In 1929 Henry Kilgus and the Reeder Lime and Stone Co. were working in the west part of the ridge to obtain stone for lime and for crushed stone. Their quarries are contiguous. The Reeder quarry has been known as the Chippewa Limestone Quarry and the lime manufactured is sold under the name of Chippewa Lime.

Quarry section, Reeder Lime and Stone Co., Hughesville

	Feet
Siliceous limestone, locally termed "hard pan"	25 to 30
Shaly limestone	8 to 12
Dense massive limestone, ranging in color from gray to dark blue	50

The beds dip northeast at an angle of about 25°. As the quarry face is being advanced in that direction the overlying shaly and siliceous limestones are increasing so that it is becoming more expensive to obtain the underlying good limestone for burning. The face of the quarry is about 80 feet high. Although the top siliceous layer is crushed and sold for highway use, this is not very profitable as the demand is so extremely seasonal and local. The lime business in the section is also less profitable than in former years because of the competition with the Michigan pulverized raw limestone that is shipped into northern Pennsylvania and southern New York. The Reeder Company has 16 kilns and did have 24 at one time. The lime is sold as lump or ground lime.

Analyses of stone burned for lime, Reeder Lime and Stone Co.

(Analyses made at Pennsylvania State College)

	Top (edge stone)	*Intermediate (fliers)*	*Bottom (block)*
$CaCO_3$	94.82	90.71	95.36
$MgCO_3$	.50	.84	.87
$Al_2O_3 + Fe_2O_3$	.58	.80	.53
Insoluble	3.87	5.85	2.34
Undetermined	.23	1.80	.90

In 1928 the Reeder Co. produced somewhat over 2000 tons of lime and almost 5000 tons of crushed stone.

Henry Kilgus has 6 kilns and produced about 1200 tons of agricultural lime in 1928.

East of the Reeder plant are two small operations in the same ridge where Edward Tule and W. E. McConnell quarry and burn lime.

At the extreme southeastern end of this ridge of Helderberg limestone is the plant of the Lime Bluff Co., formerly A. T. Armstrong and more recently Winston & Co. At one time lime was burned here and also some stone used for flagging was also obtained from this quarry. In recent years only crushed stone has been produced. The annual plant capacity is given as 45,000 tons of crushed stone. The quarry face at the highest point is 115 feet high. The quarry is well equipped with two steam shovels and adequate crushing machinery.

Several different kinds of stone are quarried. The strata worked for lime by the other companies in the region are quarried as well as less pure underlying and overlying beds. The strike of the beds is N20°W. and the dip 15°NE. It has been said that the rocks quarried average 77 per cent $CaCO_3$ and 2.75 per cent $MgCO_3$.

White Deer Valley. The area is bounded on the south and west by White Deer Ridge and on the north by Bald Eagle Mountain. The belt of Helderberg limestone crops out in a curve through Montgomery, Maple Hill, and Elimsport and then eastward paralleling White Deer Ridge.

The only quarries seen in this area are in the vicinity of Elimsport and have been operated by H. C. Baker and J. P. Best. In both these quarries the beds being worked are hard, dark blue limestone, with a few calcite veins running through the massive beds. The beds are about 20 feet thick and are made up of layers two to five feet thick.

Directly over the massive bed is a softer, lighter blue limestone which is rather siliceous and breaks with a glassy fracture. This is, in turn, overlain by a shaly limestone which is never burned for lime. The beds average about three feet thick and make a total of 20 feet. There is much evidence of cave material in both quarries.

Additional analyses of Helderberg limestones of Lycoming County

	1	2
$CaCO_3$	60.964	70.589
$MgCO_3$	30.691	1.740
SiO_2	6.960	21.680
$Al_2O_3 + Fe_2O_3$	1.330	4.660
S	.100	.027
P	.003	trace

1. Half a mile north of Jersey Shore.
2. Ferguson quarry, 2 miles west of Jersey Shore and 1 mile above mouth of Pine Creek. (3, p. 94).

In the Muncy region the Helderberg series includes an unusual type of stone that is utilized as a paint pigment or filler for machinery, cars, safes, etc. It has been described by the author (4, p.70) as follows:

"The quarry is located along the left bank of the Susquehanna River one mile south of Muncy Station, just below the Philadelphia and Reading Railroad bridge. The shale forms a part of the Lower Helderberg formation which is composed, in the main, of limestones but in certain sections includes considerable shale. At the quarry

the shale, which is of a dull dead black color, is interbedded with black argillaceous limestones, which in certain places are in the form of lenses varying from a few inches to a few feet in thickness and from 1 to 20 feet in length. The shale also contains enough $CaCO_3$ in most of the strata to produce a feeble effervescence with dilute acid. The layers of rock that contain much $CaCO_3$ are cast aside. The black color of the shale is caused by a considerable percentage of organic matter. Pyrite in the form of tiny crystals and in larger nodules occurs in the shale and these nodules are numerous enough in certain places to render the rock valueless. At the quarry the strata dip 26° in the direction of S. 8°E. In the section of shales exposed along the river bank there are certain layers in which pyrite nodules ranging in size from 1 to 4 inches are very common. Thin veins of calcite and pyrite are also occasionally encountered.

"No analyses of the rock as taken from the quarry are available but the following analysis made by Harrison Bros. and Co. of the finished product (Keystone Black Filler) probably represents the average composition of the rock better than a single analysis of a picked sample:

SiO_2	57.53	Na_2O	1.06
Al_2O_3	16.72	K_2O	2.12
Fe_2O_3	4.52	Water	3.19
FeS_2	3.76	Organic matter (carbon)	5.60
$CaCO_3$	4.12		
MgO	1.38		100.00

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Topographic and Geologic Survey Commission

4. The Mineral Pigments of Pennsylvania, by B. L. Miller, Report No. 4, Harrisburg, 1911.

No limestones have been worked in McKean County for many years, according to all accounts. The Vanport is reported to be present in the vicinity of Clermont, outcropping near the crests of the stream divides, and another limestone in the lower part of the Pocono has been described in earlier publications. Neither of these has been examined by the writer.

C. A. Ashburner working in the region over fifty years ago wrote the following description (2, p. 128) of the limestone now called the Vanport limestone:

"The Clermont (Ferriferous) limestone was first studied, and its true position in the coal measures determined in the vicinity of Clermont. I gave it this geographical name until its identity with the Ferriferous limestone should have been absolutely determined. The limestone outcrops on the Wilcox farm between Clermont and Warner brook. It consists of a bluish gray silicious limestone 6 feet ± thick and has been stripped on this farm for a number of years. The lime being used both for building and agricultural purposes. In drill hole No. 1 the limestone was pierced and reported 8 feet thick. An outcrop of the bed was found in several places near the headwaters of Instanter Creek and County Line Run. In every case the limestone was found to be very silicious and of very poor quality. With the railroad facilities in McKean County it is hardly probable that the limestone can ever be economically worked."

In McKean County in addition to the Vanport limestone there is a thin limestone near the bottom of the Pocono formation that has been noted by Rogers and Ashburner.

Rogers (1, pp. 548-549) gives the following brief description:

"Not many feet above this (the Catskill red shale) and about 200 feet below the conglomerate, are found in numerous places evidence of a persistent band of limestone. It occurs, for instance, on the hillside, near the road from Potato Creek to Tunamaguont Settlement (Bradford) and about 6 miles N. of Smethport, where a copious spring issues, charged with lime, which covers the stones and grass with a calcareous tufa. Similar springs issue upon the Warren Road, 6 miles W. of Smethport. On Bunker Hill, on the Bellefonte Turnpike, a specimen of fossiliferous limestone was found occupying this position in the series, under an exposure of very hard whitish Vespertine sandstone, dipping 7° S.S.E.

"The bed itself was discovered beneath a cliff of similar hard whitish sandstone, 30 feet high, upon the run which enters Potato Creek from the Westward, 10 miles S. of Smethport. This limestone is 4 feet thick, exceedingly fossiliferous, very hard, and very sandy, being in reality a sandstone filled with fossil shells. It will sometimes make a sufficiently good lime for agricultural purposes. It seems to have been deposited over a wide area, as we discovered it upon Bennett's Branch to the S.; while there can be no good reason to doubt that the same band makes its appearance upon the Tioga River and Pine Creek, and even on Towanda Creek to the E. It has been recognized also upon the Tunamaguont (Tuna) Creek to the N.W."

Ashburner (2, p. 68) also described the same limestone as follows:

"Marvin Creek Limestone. Near the bottom of the Pocono a well defined bed of limestone has been found to exist in every section of the county where the rocks of this part of the formation are exposed to view."

"In southern Bradford township the limestone is exposed along Shepherd Run. Here it consists of a hard bluish-gray fossiliferous limestone 2 feet thick. It is overlaid by 25 feet of gray flaggy sandstone and shale; immediately below it are found from 50 to 60 feet of greenish yellow, sandy slate.

"The greatest development of this limestone seems to be in the Marvin Creek valley.

"On the western slope of Chappel Hill, in the northern part of Sergeant Township, this limestone outcrops along the road, at an elevation of about 2080 feet. Here it is a hard siliceous and argillaceous limestone, containing fragments of fossils of Chemung type; it is 5 feet thick. Above it occur 20 feet of green and brownish-gray flaggy and shaly sandstone; below it 60 feet of olive and gray shales and shaly sandstone.

"In many places where the bed is not actually exposed fragments of the limestone may be found scattered in the soil, in the vicinity of the outcrop. Weathered portions of the stone present a very peculiar appearance. The lime leeches out leaving a silicious skeleton."

"This limestone is probably the same as the Lower Meadville limestone in Crawford County.

"In the Benezette dry hole, Elk County, a bed of limestone 7 feet thick was reported at a depth of 123 feet. This is without doubt the same as the Marvin Creek limestone.

"Nowhere has this bed been found of economical value; but from the persistency of its occurrence it forms a very important geological horizon."

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2. The Geology of McKean County, by C. A. Ashburner, Report R, Harrisburg, 1880. Contains several brief references to the Ferriferous or Clermont (Vanport) limestone in addition to paragraph quoted.

MERCER COUNTY

The limestones of Mercer County are of little economic importance although they have been utilized in a number of places on a small scale. They consist of the Mercer and Vanport limestones as shown in the section below. The Vanport is the most important but it is present in only a few places. At one time it must have had a wide development within the county but it has everywhere been removed by erosion except on hilltops in the southeastern part of the county. Remnants are preserved in Springfield, Liberty, Pine, Jackson, and Worth townships.

The Lower and Upper Mercer limestones have a much greater extent but they are thin and in most places rather impure.

Geological section of Mercer County

- Allegheny group
  - Lower Freeport sandstone
  - Upper Kittanning (Darlington) coal
  - Middle Kittanning coal
  - Lower Kittanning coal
  - Kittanning fire clay
  - Kittanning (Industry) sandstone and shale
  - Buhrstone iron ore
  - *Vanport (Ferriferous) limestone*
  - Scrubgrass coal
  - Clarion coal
  - Fire clay
  - Brookville coal
- Pottsville series
  - Homewood (Piedmont or Tionesta) sandstone
  - Tionesta coal
  - Tionesta iron shales
  - *Upper Mercer (Upper Wurtemburg) limestone*
  - Upper Mercer coal
  - Upper Mercer iron shales
  - *Lower Mercer (Lower Wurtemburg) limestone*
  - Lower Mercer coal
  - Lower Mercer iron shales
  - Upper Connoquenessing sandstone
  - Quakertown coal
  - Quakertown iron shales
  - Lower Connoquenessing sandstone
  - Sharon iron shales
  - Sharon coal
  - Sharon conglomerate
- Pocono series
  - Burgoon group
    - Shenango shale
    - Shenango sandstone
  - Cuyahoga group
    - Crawford shales
    - Sharpsville sandstone
    - Sunbury (Orangeville) shales

The table above lists only the beds that have received names due to their identification in different sections. These named strata are interbedded with many shales and sandstones not mentioned.

CARBONIFEROUS LIMESTONES

Lower Mercer limestone. So far as known the Lower Mercer limestone has not been quarried recently although it is probable that here and there it may be utilized on a small scale when it can be easily obtained. The writer has not investigated it in Mercer County as its importance did not seem to warrant special study. Therefore the existing information is mainly confined to that published many years ago when local lime burning was much more common than at present and thin limestones were worked more than now. The following notes are taken from Report QQQ of the Second Geological Survey of Pennsylvania. (2, pp. 40-42).

"The Mercer Lower Limestone is widely traceable through Mercer County, from north to south and from east to west, either as a limestone or as an iron ore bed, or both combined; although, as has been

already said, some of its reported outcrops may properly belong to the Upper limestone.

"It is always a dark gray or bluish rock, blue predominating; sometimes slaty, splitting off in thin plates or slab-like pieces; always richly fossiliferous, and especially rich in mollusks and crinoids, the broken stems of which often make up a considerable part of the mass.

"Coming from Lawrence County it is first seen at Lyle Mercer's, in south Wilmington Township, in the following section:

Lyle Mercer Section

			Ft.	*In.*
1.	Concealed			
2.	Mercer Upper coal		3	10
	Coal	2′		
	Fireclay	0′10″		
	Coal	1′		
3.	Concealed		15	
4.	Calcareous shale		2	
5.	Shales, sandy		4	
6.	Mercer Lower Limestone		3	
7.	Mercer Lower coal		2	6
			30	4

"The calcareous shale, No. 4, a sort of futile repetition of the limestone deposit below it, has been noticed nowhere in the county but here. It is full of limestone nodules, which are fossiliferous.

"The limestone is quarried to some extent, 4 feet thick, on Mr. Dick's land, near the northwest corner of Wilmington Township but slacks imperfectly.

"It roofs the Carbon Coal Company's mines on Mrs. Love's land, South Lackawannock (Township), and its light blue fossiliferous fragments surround the air shafts.

"North of Bethel, West Lackawannock (Township), Wise farm, near the Snyder Coal Company's shaft, it is quarried in two layers, 20 inches of limestone, the upper layer the purest, making good farm lime.

"Here it lies exactly 160 feet above the *Sharon Coal.*

"In Keel Ridge, Hickory Township, it underlies about 100 acres of the Hoagland and other farms; 4 feet thick, reported; 3 feet thick where exposed at the old ore drift. It is purer than usual here, and was used as flux by one of the Sharpsville furnaces, and at Clay furnace. It is a mere mass of fossils.

"West of Mercer 1½ miles, along the Mercer and Sharon road down Devil's Hollow, (Hell's Hollow), it shows itself 2 feet thick, 25 feet below the Mercer Upper Coal.

"At Mercer, just above the Newcastle and Franklin railway station, and about 100 feet above the track on McDowell's land, it has been cut in a coal drift.

"At Crill's Falls, Crill's Run, it shows itself 2½ feet thick, 10 feet below the base of the Homewood Sandstone (This must surely be the Mercer Upper Limestone.—J. P. L.). But at Painter's Mills, a short distance further north, its thickness is 3 feet, and the interval 31 feet.

"At Stoneboro, on the north shore of Sandy Lake, it is seen 70 feet below the Brookville Coal.

"Near Sandy Creek, south, and near the county line, on McClelland's land, it was once quarried for the old Reed furnace.

"At Maple Grove Coal Works, north of the last, it shows in the mine entry, varying in thickness, disappearing and reappearing over the coal.

"In Mill Creek Township, still further north, it is burned for lime in many localities, by Messrs. Blatt, Chateley, Fulk, Moore, and others.

"In French Creek Township, about 3 miles south of the Crawford line, and on its last outcrop towards the north, it was mined at Cooper's, near Deer Creek church."

Upper Mercer limestone. The same situation prevails with reference to the Upper Mercer limestone as described above for the Lower Mercer. The following description is taken likewise from Report QQQ of the Second Geological Survey of Pennsylvania. (2, pp. 36-37).

"This is the 'Mahoning Limestone' of Rogers, (Geol. of Penn., 1858) who recognized it on the Mahoning River, but not in Mercer County, where, in fact, it can only be seen at a few localities. As I found it near Mercer, while the report of Lawrence County was going through the press, I was able to apply to it in that report the less embarrassing name of Mercer Upper Limestone.

"It was once quarried at Cozad's, (about two miles west of Mercer), on the Sharon and Mercer road, at the foot of Devil's Hollow (Hell's Hollow), as flux for Oregon furnace. It here lies 30 feet over the Mercer Lower Limestone, and carries its own ore.

"At Stranahan's, a little south of the last, it appears in the following section:

Stranahan Section

	Ft.	*in.*
Sandstone, shaly	5	
Iron ore	1	
Mercer Upper Limestone	2	
Mercer Upper Coal	1	6
Concealed	25	
Mercer Lower Limestone	2	
Mercer Lower Coal	2	6
Concealed	8	
Connoquenessing Upper Sandstone, massive		
	47	

"It is here quite ferriferous. The fragments on the old dump heaps furnish many mollusks and crinoidal joints.

"When it is said above that this Upper limestone is of limited extent in Mercer County, the reservation must be made that some of the recorded exposures of the Lower limestone may be exposures of this bed. In almost every part of the county where this part of the series is well exposed, one of the limestones may be seen; but the two limestones are nowhere seen in the same section, except around Mercer, and at two other localities.

"At Painter's Mill both limestones are visible in the following section, carefully leveled by Mr. F. H. Oliphant, Jr.

Painter's Mill Section

	Ft.	in.
Mercer Upper Limestone	2	
Mercer Upper Coal	1	
Concealed	30	
Mercer Lower Limestone	3	
Mercer Lower Coal	1	6
	37	6

"In Lawrence County, (see Report QQ) where I have followed both limestones over large areas, the lower one is the more persistent of the two, and therefore, in this report on Mercer County, I have assumed its existence in preference to the other wherever I could find but one, unless I could actually measure up to the Brookville Coal bed, and a short interval made the Upper one more probable. For there is usually an interval of 70 feet or 75 feet down to the Lower, and of only 40 feet or 50 feet down to the Upper limestone."

Vanport limestone. The Vanport limestone as mentioned above is sparingly developed in the southeast corner of Mercer County, but everywhere as remnants of a much more extensive deposit at one time, now largely removed by erosion.

It is fairly well developed along Wolf Creek in Liberty Township where it is from 12 to 14 feet thick and was quarried on a moderately large scale many years ago to be burned for agricultural lime and plaster. As described in more detail in the section devoted to Lawrence County the Vanport is rather prominently divided into a lower blue portion and an upper gray one. It is everywhere characterized by the presence of numerous fossils. It is probable that some localities might be found in the vicinity of North Liberty where this limestone might be quarried with profit if it were not for the keen competition of the extensive quarries of Butler and Lawrence counties.

In Springfield Township the Vanport is present in a very small area almost on the Lawrence County line south of Leesburg where it occurs in two hills. It is about 15 feet thick and was quarried at one time. It has also been reported in the southeast corner of Springfield Township.

In Pine Township the Vanport is present in at least three areas. The first is east of Swamp Root and extends east into Butler County. The upper portion has largely been removed by erosion but about 7 feet still remain. It was at one time extensively quarried here and burned for lime. A second area lies about 2 miles northeast of Grove City, where some quarrying has been done within recent years. The third is about 4 miles northeast of Grove City.

The Vanport is reported to be present in a few isolated knobs on the north border of Findlay Township and on a single hill in the extreme northwest corner of Wolf Creek Township.

Two areas of Vanport limestone have been reported in Worth Township. One is a high knob at Henderson, where a small area remains. It was once quarried and burned there and is said to be 8 feet thick. The other occurrence is in a high knob in the extreme southeast corner of the township. The Vanport occurs in isolated patches in the tops of the hills about 5 miles east of Mercer in Jackson Township. The rock here outcrops on both sides of the north-

south highway and has been quarried for burning. Eight feet of good quality gray limestone is exposed in the old quarry and was quarried some 50 years ago. The total thickness is not now visible. One-eighth of a mile to the southwest a drill hole on the farm of J. A. Barnes revealed 14 feet of limestone beneath a cover of glacial debris 11 feet in thickness.

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MIFFLIN COUNTY

The limestones of Mifflin County are widely distributed and are found in every township with the exception of Bratton. They belong primarily to the Cambro-Ordovician and Helderberg (including Tonoloway) formations, although some limestones have been found at other horizons, especially the Marcellus.

As in the case with other sections of the State, there has been a gradual change in the utilization of the limestones of the county. At one time small quarries were opened in many places to supply stone for burning for agricultural and plastering lime and in some instances for building stone. When the iron mines of the region were in operation somewhat larger quarries were operated in the vicinity of the furnaces for fluxing stone. The present usage is to work local quarries to furnish the necessary crushed stone for building highways and various concrete structures, and large quarries for the shipment of fluxing stone, crushed stone, and lime. A small amount of stone is still quarried and used locally.

The major operations are in the vicinity of Naginey where the Bethlehem Mines Corporation, a subsidiary of the Bethlehem Steel Co., and the National Limestone Co. have large mines.

CAMBRO-ORDOVICIAN LIMESTONES

The Cambro-Ordovician limestones of Mifflin County are found in Kishacoquillas Valley, a canoe-shaped valley somewhat more than 30 miles long and approximately 3 to 4 miles wide, that extends southwest across the northern part of the county and a few miles into Huntingdon County. At the western end it comes to a point but the eastern portion breaks up into three fingers or prongs known as Havice, Treaster, and New Lancaster valleys. The major part of the valley is drained by Kishacoquillas Creek, which flows east to Reedsville where it turns sharply and flows southward through a gap in Jacks Mountain to join Juniata River at Lewistown. Honey Creek with its tributaries drains the eastern part of the valley and the three subordinate valleys. A considerable part of the valley has no surface streams as the cavernous character of the limestones facilitates drainage by underground channels. A number of small streams running down the sides of the enclosing mountains disappear in limestone sinks. Formerly a large cave at Naginey could be entered but the mouth has now been filled in the process of quarrying by the Bethlehem Mines Corporation. Nearby are the Alexander Caverns discovered in 1926 and opened to the public somewhat later. These are as fine as any cave in the State.

The strata constituting the limestone valley were thrown into an upward fold (anticline) during the Appalachian revolution. Erosion has now removed the overlying strata and exposed the limestones beneath the old anticlinal ridges. On both sides the limestones dip toward the mountains. Shales of Martinsburg (Hudson River) age form the lower slopes of the enclosing mountains and the still younger Oneida and Medina sandstones and conglomerates, because of their

greater resistance to erosion, compose the higher mountain ridges. There are a few minor folds and the subordinate valleys at the eastern end owe their existence to the breaking up of the major fold into three smaller anticlines. With such arrangement the oldest strata are found at the top of the anticline, which is not far from the center of the valley, and the upper and younger beds are at the sides. This simple structure is important to recognize for any one who is in search of any particular series of beds.

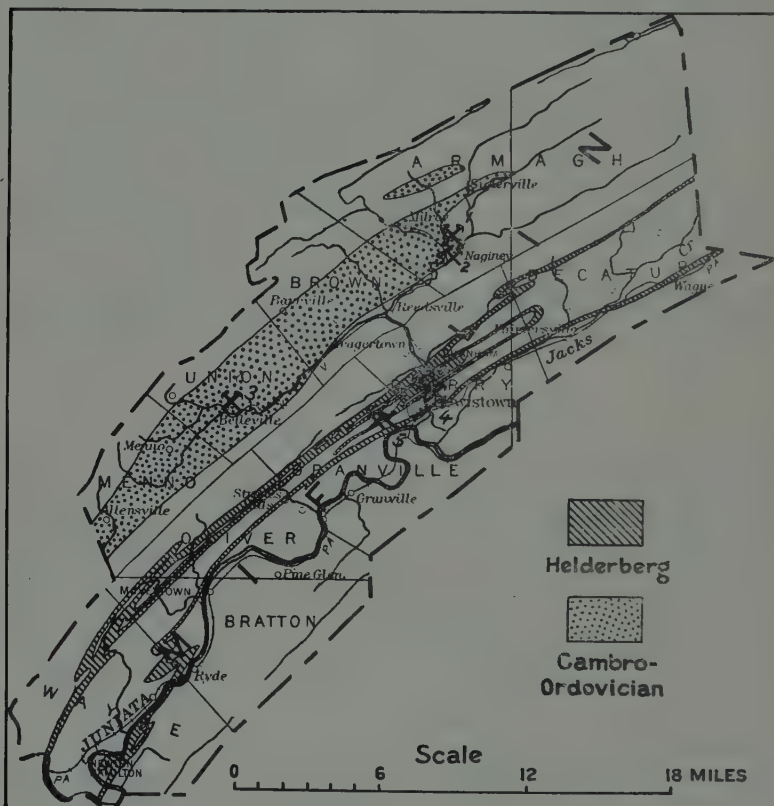

Fig. 25. Limestone areas in Mifflin County.

1. Bethlehem Mines Corporation.
2. National Limestone Co.
3. Union Township quarry.
4. Mifflin County Lime & Stone Co.
5. Ralph Aurand.

The limestones of the region have not been mapped as distinct formations as in Centre County, yet there is little doubt but that the same classification could be applied here. The search for low-silica stone throughout the valley by the steel companies has shown the presence of the Black River group, particularly the Lowville, and the overlying shaly beds of the Trenton and the underlying dolomitic and more highly siliceous strata. All the work that has been done seems to show that it is useless to look for any of the low-silica lime-

stones except near the margins of the limestone belts, where the limestone passes beneath the Ordovician shales.

The major portion of Kishacoquillas Valley lies in Mifflin County. This is one of the finest agricultural valleys of the State, and contains many beautiful and well-kept farms. The prosperous appearance of the region bears witness to the fertility of the soil as well as the thriftiness of the Amish farmers. Although the valley is mostly underlain by limestones the farmers in the past burned much lime for home consumption. Perhaps the major portion of the farms of the valley have one or more excavations where small quantities of limestone have been taken out. Many roadside cuts also expose the limestone. All of the stone observed seemed to be fairly high in magnesia and much of it has the appearance of being fairly high in silica. It is not at all improbable that careful search might reveal the presence of low-silica and even low-magnesian limestone in the different parts of the valley. The only working quarry seen in 1929 west of Milroy was a small one in the north part of the town of Belleville where stone was being obtained for township use.

Several farmers have burned limestone during recent years and others contemplate digging stone for their own use when farm work is slack. In general, the farmers use less lime now than formerly and most of the lime is shipped in or hauled by wagon from the National Lime Co.'s plant at Schrader, near Naginey.

Near the extreme northeast end of the valley, there are two very large operations of the Bethlehem Mines Corporation and the National Limestone Company. The largest quarry in Mifflin County is that of the Bethlehem Mines Corporation (subsidiary to the Bethlehem Steel Co.) located about 2 miles east of Milroy on a branch of the Pennsylvania Railroad. The quarry has been open since 1906 and operated by the present owners since 1923. There are two quarries on the property, one of which has been abandoned. The active one is about 2300 feet long, 200 feet broad, and has a working face about 80 feet in height. The strata worked are partly about the end and partly along the side of a synclinal fold, which pitches N45°E. The strike of the beds varies from N45°W. to N45°E. with a dip of about 15° NE. or SE. There has been some minor faulting. The stone is mainly dark gray. The average composition of the beds quarried is as follows: $CaCO_3$, 92.50; $MgCO_3$, 3.80; $Al_2O_3 + Fe_2O_3$, 1.95; SiO_2, 2.75.

The quarry is opened in the side of a hill and is worked almost to water level. The cavernous character of the stone in the region would forbid deeper working because of excessive water. There are some important caves in the region and occasional sink holes. The stripping is light. The plant is well equipped with electric shovels and haulage, crushers, screens, and washing plant. The annual capacity of furnace flux is about 600,000 tons and of the washing plant for commercial stone is 85,000 tons. The production of the quarry 1906 to 1930 has been 6,210,000 tons of fluxing stone and 104,000 tons of commercial stone. The latter item covers only three years.

The National Limestone Co. also operates on a rather large scale near Naginey. Schrader is the name of their shipping station. Three quarries have been worked but one, known as the Alexander quarry,

was idle in 1929. There are several kinds of stone in the property, some has less than 2 per cent silica and is adaptable for fluxing stone and lime, and the balance is higher in silica but excellent for crushed stone. The annual production capacity is stated to be 105,000 tons crushed stone, 50,000 tons fluxing stone, and 4,000 tons of hydrated lime. There are 5 lime kilns.

The face in the principal quarry is about 200 feet long and 100 feet high. The lowest stone in the quarry is a massively-bedded, bluish-black limestone suitable for flux. This is separated from an overlying thick band of grayish-blue, siliceous limestone by about 3 feet of shaly limestone or mud. Another similar mud seam lies above and is overlain by alternating layers of stone of varying composition from low-silica stone satisfactory for fluxing purposes to high-silica stone suitable only for crushed stone. Fossils and stylolites were observed on weathered surfaces.

In part of the quarry there is complicated structure involving a prominent anticlinal arch, an overturned fold, and a fault.

The following analyses furnished by the company show grade of stone obtained from the Alexander quarry. Sampling of the large quarry now in use would show similar materials.

Alexander quarry, National Limestone Co., near Naginey

Analyses of individual samples.

Sample No.	Thickness		Silica	Alumina	Iron	Lime	Magnesia	Phos.
	Ft.	In.						
1-A	6	0	.70	.46	.10	54.60	.65	.003
1-B	2	6	1.00	.99	.15	53.70	1.00	.003
*1-C	--	4	9.00	3.92	.55	47.00	1.22	.008
1-D	3	0	1.20	.59	.15	53.70	.93	.003
*1-E	2	6	28.40	5.22	.55	30.30	3.23	.010
1-F	2	6	1.60	.94	.15	52.80	1.44	.004
1-G	2	6	2.40	1.32	.20	52.00	1.11	.004
1-H	2	9	3.20	1.42	.20	51.50	1.58	.004
1-I	2	5	1.50	.24	.15	53.70	1.07	.003
1-J	3	3	5.00	2.77	.30	47.00	3.01	.006
1-K	2	4	3.00	.52	.20	52.90	.78	.005
1-L	2	6	1.60	.99	.15	51.70	1.94	.003
1-M	2	6	1.40	1.02	.20	51.60	2.51	.003
1-N	2	0	2.30	1.12	.20	52.60	1.14	.005
1-O	2	5	1.40	.72	.20	51.30	3.23	.012
Average	-----	-----	1.94	.97	.18	52.72	1.32	.004

Sample No.	Thickness		Silica	Alumina	Iron	Lime	Magnesia	Phos.
	Ft.	In.						
2-A	6	0	.80	.59	.15	54.20	.78	.003
2-B	6	0	1.00	.86	.10	53.20	1.45	.002
2-C	2	6	.80	2.52	.20	53.70	.21	.002
*2-D	--	4	12.40	4.43	.40	43.40	2.44	.006
*2-E	3	0	6.40	3.96	.45	48.20	1.44	.005
2-F	1	9	1.60	1.42	.20	52.80	1.22	.003
2-G	5	0	1.60	.72	.20	52.90	1.47	.003
2-H	2	6	4.40	2.65	.25	49.70	1.90	.005
2-I	4	0	1.80	2.45	.25	50.70	2.33	.005
Average	-----	-----	1.54	1.37	.18	52.98	1.31	.003

Sample No.	Thickness Ft.	In.	Silica	Alumina	Iron	Lime	Magnesia	Phos.
3-A	9	0	1.20	1.49	.15	53.00	1.25	.004
3-B	10	0	.80	.86	.10	53.60	1.25	.002
3-C	2	10	.40	.46	.10	53.40	1.83	.003
3-D	2	10	1.50	.46	.10	53.00	1.61	.003
3-E	2	0	1.00	.72	.20	53.50	1.25	.003
*3-F	1	0	10.00	3.80	.35	46.00	1.28	.006
*3-G	3	0	11.20	4.03	.40	44.60	2.40	.007
3-H	2	0	1.60	.79	.15	53.10	1.28	.003
3-I	4	6	1.50	2.79	.15	51.90	1.40	.003
3-J	3	2	5.00	1.65	.25	47.10	4.27	.009
3-K	4	9	2.00	.72	.20	51.00	2.83	.004
3-L	4	0	1.50	1.42	.20	51.20	2.69	.004
3-M	3	0	2.40	.79	.15	51.10	2.49	.003
Average			1.56	1.20	.15	52.50	1.82	.0035

Sample No.	Thickness Ft.	In.	Silica	Alumina	Iron	Lime	Magnesia	Phos.
4-A	12	0	.60	.25	.10	54.50	.86	.002
4-B	2	10	.60	.46	.10	54.50	.72	.002
4-C	3	0	.80	1.09	.15	53.40	1.22	.002
4-D	1	2	2.40	.72	.20	52.60	1.28	.003
*4-E	3	0	20.40	4.09	.50	40.40	1.54	.007
4-F	2	5	2.40	1.32	.20	52.20	1.36	.003
4-G	4	6	3.40	.65	.25	51.10	2.15	.003
4-H	3	2	5.00	2.25	.25	48.40	2.82	.004
4-I	4	9	2.00	1.19	.15	53.00	1.15	.004
4-J	3	0	1.60	.72	.20	51.20	2.95	.004
4-K	4	0	1.60	.99	.15	50.40	2.87	.004
Average			1.75	.83	.15	52.67	1.53	.003
Quarry average			1.82	1.06	.16	52.60	1.53	.003

* The beds represented by these samples are not quarried for furnace use and are not included in above averages.

Some limestones on the Close farm at Siglerville were sampled by the Cambria Steel Co., but there is no quarry there. In 70 samples the silica ranged from 0.44 to 20 per cent, averaging about 4 per cent. Some shaly layers are high in silica. Magnesia is low in all but a few samples, thus indicating the upper limestone strata.

On the south side of the Belleville road half a mile west of Reedsville where there are a few small openings, 23 samples were taken and analyzed for silica. They show a range from 0.80 per cent to 7.48 per cent, averaging 3.09 per cent. The beds are thought to lie below the horizon of the best stone.

Along Coffee Run about midway of Kishacoquillas Valley nearly horizontal limestones of rather poor quality are exposed. The lower 34½ feet average 3.10 per cent SiO_2 and the overlying beds considerably higher.

At Woolen Mills on Coffee Run there are exposures of poor quality limestone. About 1500 feet down stream from the mills some fair stone is exposed. The 17 samples analyzed showed a range of silica from 0.52 per cent to 8.82 per cent, averaging 3.08 per cent. The samples collected represent about 90 feet of beds. Some intervening beds amounting to about 50 feet are concealed. The beds dip 40°S.

At Union Mills good limestone is exposed along Kishacoquillas Creek but conditions are not favorable for quarrying.

One mile east of Belleville on the north side of the road a small quarry exposes about 25 feet of stone of poor quality, containing

considerable black flint. South of the road poor stone is exposed dipping about 25°W.

In 1929 the Union Township supervisors were working a quarry in the north part of Belleville under lease from S. D. Peechey and Son to obtain crushed stone for the township roads. Their announced plan at that time was shortly to abandon the quarry and purchase the needed stone at Naginey. Several different varieties of stone are exposed. Some layers are extremely fine grained, brittle, break with a glassy fracture, and appear to be fairly low in both silica and magnesium. Other layers are extremely hard and tough and decidedly dolomitic. Considerable chert was noted in certain beds. The bedding plane surfaces are very uneven, indicative of shallow water deposition. Edgewise conglomerate is fairly common. The beds strike N51°E. and dip 24°NW.

About Belleville and Allensville, the farmers still burn some lime in heaps for their own use although considerable high grade lime is shipped in as well as some pulverized limestone.

At the north edge of Allensville a small amount of stone was recently taken in an old quarry for foundation use. Menno Township also recently obtained some stone for the township roads from a quarry north of Allensville. There are a number of old quarries southwest of Allensville, mainly on the southeast side of the highway, but all appear to have been idle for many years.

The first four analyses that follow are taken from Vol. MM (2, p. 308) of the Second Geological Survey of Pennsylvania and the exact location of the quarries is uncertain.

Analyses of Cambro-Ordovician limestones of Mifflin County

	1	2	3	4	5a	5b
$CaCO_3$	97.651	81.178	70.214	54.285	43.30 to 77.17	55.87
$MgCO_3$	1.131	13.498	24.415	36.109	17.55 to 40.96	34.71
SiO_2	------	------	------	------	3.33 to 9.24	6.29
$Al_2O_3+Fe_2O_3$	0.426	1.253	1.360	1.422	1.02 to 3.92	2.02
S	0.034	0.054	0.034	0.151	0.04 to 0.13	0.07
P	0.039	0.025	0.016	0.011	0.007 to 0.018	0.11
Insoluble	0.760	4.530	4,050	8.010	------	------

1. Douglas Campbell quarry, two miles from Belleville. Fossiliferous limestone from top of II. Specimen sparkles with calcite; slightly coated with iron oxide, light bluish gray, with rough fracture.

2. Andrew Campbell quarry. Mottled black and gray limestone with drusy cavities.

3. Andrew Campbell quarry. Light bluish gray limestone; rather hard and tough.

4. Greenwood Ore Bank limestone. One mile from Belleville. "Magnesian limestone." Hard and tough; sparkles with calcite; dark bluish gray.

5. Taylor farm upper end of Reedsville. a. range of 16 samples; b. average of 16 samples. These samples seem to represent strata below the Lowville. Analyzed by H. A. Hosmer.

DEVONIAN LIMESTONES

Helderberg limestones. The Helderberg (including Tonoloway) limestones outcrop along the sides of the narrow valleys that are such a prominent feature of the topography of the southern part of the county.

These limestones extend entirely across the eastern part of the county in two narrow bands that zig-zag in places due to intricate folding. There are also a few outliers. The northern belt runs in

a rather straight line through Decatur Township to the Derry Township line where it turns east a mile due to a synclinal fold. It then turns southwest, crosses Kishacoquillas Creek, and continues to the Huntingdon County line a short distance below Mt. Union.

The southern band is more regular. Entering from Snyder County, it passes southwest forming a valley in which the towns of Wagner, Paintersville, Maitland, Lewistown, Strodes Mills, and McVeytown are located. It crosses Juniata River below Newton Hamilton.

Along Kishacoquillas Creek near Lewistown two divisions were noted by the geologists of the Second Geological Survey. The upper is about 140 feet thick and consists of flaggy argillaceous limestones that have been quarried somewhat for building purposes. Some lime has been made from them but it is of poor quality. The lower member, about 185 feet thick, is composed of more massive beds of blue limestone and was called the Lewistown limestone by the Second Geological Survey. This member has been quarried extensively for lime and in the past for furnace flux, especially the upper 60 feet that represents the best grade.

Reeside (4, pp. 212-214) has studied this region in detail and has published the following section.

Section on Kishacoquillas Pike, at Mount Rock, Lewistown

	Thickness in feet
Helderberg limestone:	
New Scotland limestone member:	
Limestone, very dark, impure, fissile	3.0
Shale, weathered brown, very fissile; contains some bands of very dark impure limestone	10.4
Limestone in two beds (12 and 9 inches) separated by shale (9 inches), fine grained, blue-gray, crystalline	2.5
Limestone, single bed, light gray, cherty, fine grained; some calcite cleavage faces show; does not scratch hammer	2.6
	18.5
Coeymans limestone member:	
Shale, weathered, brown	.6
Limestone, single bed, light gray, cherty	2.3
Shale, weathered, dark gray, calcareous; limestone bands and large nodules	1.5
Limestone, massive, sandy, crystalline, blue; some black chert nodules; very tough, hard rock	6.2
	10.6
Keyser limestone member:	
Limestone, dark gray, fine grained, thin bedded	1.0
Limestone, massive, dark gray, fine grained; conchoidal fracture	2.0
Limestone, shaly, yellow, weathered	1.0
Limestone, massive, dark gray, impure fine grained; conchoidal fracture	2.5
Shale, weathered	2.0
Limestone, light gray, solid, fine grained; conchoidal fracture	1.0
Limestone, platy, dark gray, impure	3.0
Concealed	5.1
Limestone, platy, light gray, impure, fine grained; conchoidal fracture	2.0
Concealed	6.2
Limestone, impure, platy, yellow; weathered much and poorly exposed	3.8
Limestone, platy, impure, weathered, yellowish	4.0
Limestone, massive, light gray; conchoidal fracture	1.5
Limestone, thin bedded (2 inches), dark gray; conchoidal fracture	1.0
Concealed	16.6
Limestone, banded; conchoidal fracture	.5
Concealed	1.0
Limestone, very impure	2.0
Limestone, thin bedded, fine grained, dark gray, impure, poorly exposed	4.0
Limestone, impure, dark gray, thin bedded, fine grained	4.3

	Thickness in feet
Keyser limestone member—Continued.	
Concealed	5.9
Limestone, very shaly, with purer fine grained light gray bands	2.8
Limestone, very coarsely nodular (4 to 6 inches) light blue-gray; conchoidal fracture. Shale between nodules	3.2
Limestone, thin bedded, blue-gray, crystalline	2.9
Limestone, massive; in part light blue gray, fine grained; in part subcrystalline	2.4
Limestone, thin bedded (2 to 6 inches), fine grained, light bluish gray; conchoidal fracture	7.1
Limestone, impure, shaly, alternating with harder layers, each in about 6-inch courses	3.4
Concealed	4.2
Limestone, shaly, impure, with hard layers of more resistant rock	1.7
Limestone, dark gray crystalline	5.1
Limestone, thin bedded (1 to 6 inches), light blue-gray, fine grained, impure; has shale laminae between the layers and several small lenses of brown weathered chert	5.8
Limestone, massive, nodular, impure, dark gray	8.3
Limestone, massive, dark gray, impure, not very nodular	4.1
Shale, weathered, yellow	0.5
Limestone, very nodular, impure, shaly, gray; many of its fossils are silicified	2.4
Limestone, massive, somewhat nodular, dark gray, subcrystalline, impure	2.8
Limestone, very nodular, impure, dark gray, weathered	1.8
Limestone, massive, not nodular, dark gray, coarsely crystalline	1.6
Limestone, nodular, impure, weathered; bastard limestone with occasional thin lenses of black chert	2.6
Limestone, crystalline, dark blue, thin bedded, with shaly laminae	2.0
Limestone, crystalline, dark blue, pure, massive, not nodular	1.9
Limestone weathered, very nodular	4.4
Limestone, massive, blue gray, coarse, crystalline crinoidal; weathers thin bedded in upper part	9.4
Limestone, single massive bed, pure, dark gray, coarsely crystalline and crinoidal in part; fine grained and curly in other parts	6.2
Limestone, nodular, impure, weathered; crystalline on fresh fracture and blue-gray	.9
	157.9
Tonoloway limestone	
Limestone, rather massive, fine grained pure, dark gray, almost a blue black; conchoidal fracture	6.4
Limestone, thin bedded (1 inch); much like unit above, but less massive and resistant; looks fairly solid where entirely unweathered; pure	13.4
Limestone, solid-looking, heavy bedded, gray	5.0
Shale, weathered	.5
Limestone, fairly solid, gray, in three beds (18, 12, 12 in.) separated by shale	3.5
Limestone, gray; weathers into small blocky fragments and has a somewhat nodular appearance	4.0
Limestone, thin bedded, gray	2.0
	34.8

The Helderberg limestones have been most extensively quarried near Lewistown and between Lewistown and Reedsville. In this vicinity the Logan Iron and Steel Co. formerly worked a large quarry that contained 60 feet of excellent stone for flux. A partial analysis gave the following results: SiO_2 1.580, Al_2O_3 1.004, Fe_2O_3 .237, P .016.

One mile north of Lewistown the Mifflin County Lime and Stone Co. has operated a quarry to obtain stone for agricultural lime and for road metal. A considerable part of the stone is high in silica. Nearby the Lewistown-Reedsville Trolley Co. worked a quarry in the same beds for crushed stone for concrete and highway construction. Most of the stone is excellent for this purpose as it is hard and tough and certain beds are siliceous. A few shaly beds are present.

At and near Maitland Gap several quarries have been worked for lime. At the quarry of John Goll six samples taken from the 65-foot thickness of good stone in massive beds gave the following results when analyzed by the Cambria Steel Co.:

Analyses of Helderberg limestone near Maitland Gap

	Range	Average
$CaCO_3$	94.77 to 97.00	96.00
$MgCO_3$	1.03 to 1.99	1.50
$Al_2O_3 + Fe_2O_3$ ...	0.40 to 1.04	0.70
SiO_2	0.76 to 2.26	1.15
S	0.02 to 0.12	0.045
P	0.004 to 0.009	0.006

These beds overlain by shaly limestone and underlain by shaly cherty limestone dip into the hill and could only be worked extensively by underground mining. The same beds are exposed all the way to Paintersville.

Westward the Helderberg limestones have been quarried in many places between Lewistown and McVeytown and in fewer places in the southwest corner of the county near Newton Hamilton.

Along the main highway which follows Ferguson Valley from Burnham to Town Creek the Helderberg limestone outcrops near the crest of a line of small hills parallel to but much lower than Big Ridge. At many different places small abandoned quarries and old stone limekilns were observed and doubtless there are many others concealed in the scrub growth that covers these slopes. Only one operating quarry was found. This is located 3 miles northwest of Lewistown. At this point, Ralph Aurand has recently worked some stone for the township roads and has also burned lime for the use of himself and neighbors. The quarry exposes about 30 feet of strata dipping S30°. The upper layers are massive but there is considerable surficial clay mixed with the stone. The lower layers are harder, fresher, blue stone but in thin layers, mostly under 3 inches thick.

We were told that a few years ago some farmers in this vicinity had burned a few heaps of lime but in general local limestone burning has ceased.

Along Town Run about one mile northwest of McVeytown an old quarry where lime was once burned has recently been worked to obtain crushed stone for highway use. The stone is a thin-bedded blue limestone with some interbedded shaly limestone. Some layers contain considerable chert. A slight fold is exposed but in general the beds dip steeply to the south.

Following the William Penn highway from McVeytown to Mount Union numerous outcrops of the Helderberg limestone can be seen along the road and in the adjoining fields. Occasional old quarries and kilns were noted but there is no indication of any recent working.

Marcellus limestone. Many years ago the Marcellus limestone was quarried in Wayne Township. The following descriptions are taken from Report F3 of the Second Geological Survey of Pennsylvania (2, p. 307).

"The Norton quarry, opened along the north bank of the river one-half mile east of Newton Hamilton, exhibits this limestone 40 feet thick, where it has been quarried to some extent from the bottom of the synclinal basin. It shows a hard gray crystalline and somewhat siliceous limestone, in flat beds from 2 feet to 4 feet thick, dipping perhaps 5° southeast and separated by only few inches of shale from the top layer of the Oriskany sandstone, which is exposed in the

bottom of the quarry. This opening has been developed at different intervals for the past 25 years, both for lime purposes and for paving blocks for street use in Newton Hamilton.

"The same gray Marcellus limestone has been burned at Dysart's between the canal and the railroad further east; at Samuel Postlethwaite's near Union Mills, and at John Miller's upper farm on the south side of the river, where a large amount of paving flags has been obtained."

Onondaga limestone. The Onondaga limestone, while probably of no commercial importance in this county, is known to occur. It is best exposed at McVeytown as described by Kindle.

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MONROE COUNTY

Practically all the limestones of Monroe County are confined to the extreme southeast border where two more or less parallel bands cross the Delaware River near Bushkill, pass southwestward through Stroudsburg, and leave the county a short distance beyond Kunkletown. The more southerly of these bands is the Helderberg (including Tonoloway) group, designated as "Lower Helderberg" by the geologists of the Second Geological Survey of Pennsylvania, and the Onondaga, called by the same Survey "Upper Helderberg" or "Corniferous." In addition to these well defined limestone horizons, there are some shaly limestones in the Hamilton formation.

The limestones of Monroe County have been used almost entirely to burn for the production of agricultural lime, an industry that has been declining for many years. Within recent years the quarries have been worked mainly for crushed stone for highways and concrete structures. A limited amount of stone of high quality has been taken to cement plants in Northampton County. A project has been proposed to quarry some of the dark-colored Helderberg limestones for black marble. It has been shown that they are sufficiently crystalline to take a high polish and thus produce a very pleasing effect. The chief difficulty would be to secure blocks of dimension sizes of uniform character.

HELDERBERG LIMESTONES

The Helderberg group extends in a narrow band entirely across the southern part of Monroe County. They appear at Decker's Ferry and continue southwest, close to Delaware River, to Delaware Water Gap and thence in a small valley parallel and a short distance north of Kittatinny (Blue) Mountain to the Carbon County line.

Throughout the area designated these limestones have not been recognized by continuous outcrops on account of the heavy cover of glacial debris and talus derived from the Oriskany sandstone ridge along the south side of which the Helderberg outcrops and beneath which it disappears, as the strata almost uniformly dip northward.

I. C. White in his report on Monroe County (2) has given an excellent description of the Helderberg group from which the following extracts are taken. At the time White did his work in the region, much better exposures existed than at present, due to more numerous active quarries. White recognized several divisions of the Helderberg as given on a previous page. He gives the following generalized section along the Delaware and Lehigh Rivers (2, pp. 121-129).

Generalized section on the Delaware River

	Feet
1. Oriskany sandstone, consisting of alternating beds of quartz conglomerate, and calcareous chert	50
Lower Helderberg	
2. Stormville calcareous shales, ashy, or dark gray, fossiliferous, sometimes cherty and containing limestone at base	160

		Feet
3.	Stormville conglomerate, alternating beds of quartz conglomerate, and siliceous pebbly limestone	25
4.	Stormville limestone, cherty, sandy, massive beds, containing numerous fossils, *Pentameras galeatus*, *Stromatopora*, *Favosites*, and *Receptaculites* being especially numerous	75
5.	Hydraulic cement bed ("Peth stone" of Cook)	5
6.	Decker's Ferry limestone, bluish, shaly, containing vest numbers of *Leperditia alta*, at top	20
7.	Decker's Ferry sandstone, a very hard, pebbly, often calcareous sandstone, filled with fossil shells, *Aviculas*, *Chonetes*, and others	15
8.	Decker's Ferry greenish shales, sometimes calcareo-siliceous	15
9.	Bossardville limestone, divisible into two well marked subdivisions, (a) of 65′ and (b) 25′; the upper (a) almost non-fossiliferous, dark blue, or almost black, splitting into slate-like, thin, layers; the lowest (b) dark-gray, always presenting a banded or striped appearance, and often exhibiting a true columnar structure (Stylolites); thickness of both a and b	90
10.	Poxono Island shales, buff, calcareous and magnesian	200
11.	Poxono Island limestone, bluish-gray, very compact, fossiliferous, extending down to the bottom of the Lower Helderberg on top of the Clinton red beds	5
	Total of Lower Helderberg	610

White believed that the (lower) Helderberg thinned out to the west, being replaced by the deposition of sediments that form a part of the Oriskany formation.

Of the series as given above, the only strata possessing much economic value is the Bossardville limestone, that is probably to be correlated with the Tonoloway limestone of Silurian age and by the recent classifications is not a part of the Helderberg group. For the present purpose, however, it is described (2, pp. 141-145) as part of the Helderberg.

"All the great limestone quarries of Monroe are in this rock, and it furnishes practically all the lime burned in the county.

"Its top comes out of the Delaware River just above Decker's Ferry and it is quarried at the roadside on the bluff of the river west of the ferry.

"The thickness of the interval varies from 75 feet to 100 feet and is divisible into two portions, an upper and a lower, which are very unlike in aspect and composition. The upper or quarry portion is usually about 65 feet thick and has a prevailing dark color, sometimes almost black, the extreme upper portion excepted, which is generally gray or bluish-gray; through the dark portion especially radiate seams of calcite; the rock breaks with a very sharp angular fracture and has a thin flag-like bedding, and is entirely non-fossiliferous, if we except minute dark specks which may be *Beyrichii*.

"This quarry portion of the Bossardville limestone is the only limestone bed of No. VI which extends through from this district to the Lehigh River. The Bossardville limestone has a thickness of 30 feet to 40 feet where it crosses the Central R. R. of New Jersey, one mile below Bowman's station. It possesses the same physical characters there that distinguish it in Monroe.

"Samples of the Bossardville quarry limestone were collected at several localities, and analyzed in Mr. McCreath's laboratory at Harrisburg:

Analyses of Bossardville limestone

	I	II	III	IV
$CaCO_3$	94.285	87.928	82.732	96.267
$MgCO_3$	1.528	1.937	2.830	1.384
$Al_2O_3 + Fe_2O_3$	0.700	2.110	1.360	0.840
S	0.056	0.229	*.695	0.113
P	0.014	0.019	0.007	0.010
Insoluble residue	2.850	7.860	11.930	4.250

	V	VI	VIII	VIII
$CaCO_3$	93.875	88.821	94.285	92.196
$MgCO_3$	1.309	2.345	2.118	2.171
$Al_2O_3 + Fe_2O_3$	0.680	0.710	0.540	1.100
S	0.153	0.207	0.207	0.154
P	0.010	0.013	0.015	0.020
Insoluble residue	3.920	7.650	3.020	4.260

* Average of two determinations.

"I, II. From Bossardville quarries. Hamilton Township, Monroe County.

"III, IV, V, VI, from C. Van Auken's quarry, Middle Smithfield Township, Monroe County.

"VII, VIII. From J. H. Brown's quarry, Smithfield Township, Monroe County.

"The limestone from this horizon burns readily into a light gray lime, much valued for agricultural and building purposes, though it is seldom white enough to be used for plastering. At Bossardville and vicinity, several hundred thousand bushels are annually burned and hauled far and wide into the surrounding country.

"The opinion prevails among the farmers that this limestone is occasionally absent for long distances, coming in again suddenly; thus for instance, no quarry of it has been opened between that near Experiment Mills, on Brodhead, and one mile west of Stormville in Hamilton Township, a distance of nearly five miles; hence the farmers along this line believe it absent. The truth is that there are no natural exposures here because the limestone is buried by drift and surface debris, shed from the steep slope of Walpack (Godfrey's) Ridge, since its line of outcrop would nearly always be found down along the northern margin of Cherry Valley. Hence this valuable limestone is very probably present on every farm, but covered up. The farmers owning land along the northern margin of Cherry Valley, should do some judicious digging in order to test the matter.

"In passing southwestward from Bossardville, this limestone's outcrop is again covered up by the vast heaps of Oriskany debris, and is not seen again until we pass west from Saylorsburg into Ross Township. There in the vicinity of Samuel Lessig's, the Bossardville limestone has been quite extensively quarried, though it is not so thick as usual nor so pure, and has been so much crumpled and folded as to have slaty cleavage and aspect, being in fact partially metamorphosed.

"From the vicinity of Lessig's, this limestone is not seen again until we come to the neighborhood of Kunkletown, in Eldred Township, its outcrop being constantly concealed under the surface debris, principally of Oriskany sandstone. West from Kunkletown, however, the great Oriskany beds are disintegrated, and the limestone then comes out to the surface, where it is quarried, and burned quite extensively. It is much twisted and contorted, however, so that it is

difficult to decide which way the dip is going. It is of course possible that the limestone may be entirely absent in the intermediate spaces where it makes no appearance on the surface, but the probabilities are that it is present, concealed under the great heap of debris.

"The lowest 25 feet of the Bossardville limestone is very different in aspect from that portion usually quarried for lime, having a dark-gray color, and a peculiar banded appearance made by fine lines of lamination of different colors, gray, whitish, blue, etc. It also often possesses a genuine columnar structure which is finely shown at the Experiment Mill's quarry, above the Delaware Water Gap, where the rock exhibits a prismatic structure, like basaltic columns. This structure does not exist all through the 25 feet, but is confined to certain layers, the one exhibiting it most decidedly coming 7 feet above the base of the stratum and having a thickness of 3 feet. The columns or stylolites are inclined to the southeast at an angle of 75°, while the dip of the rocks is only 35° in the same direction; thus it is probable that the structure in question has originated through the action of the forces that produce cleavage, because the rocks which exhibit it show no traces of overheating.

"The same structure is seen just below the falls at Shawnee in Smithfield Township, though the limestone exhibiting it there comes higher in the series than the one at the base of the Bossardville beds. This stratum, in physical appearance, answers perfectly to the description of Prof. Cook's Ribbon limestone which is found at the base of the series in New Jersey; although many of the layers in the Stormville limestone often possess the ribboned aspect.

"A specimen of the columnar limestone, from the Experiment Mill's quarry, had the following composition, as analyzed by Mr. McCreath: $CaCO_3$, 73.428; $MgCO_3$, 2.648; $Al_2O_3 + Fe_2O_3$, 2.970; Insoluble residue, 20.240.

"From this analysis, one might infer that it would make a pretty fair hydraulic cement, and I was informed that the limestone was tested for that purpose on one occasion at Bossardville, where it shows under the quarry limestone. It is reported as having made a very good hydraulic cement."

Stormville hydraulic cement bed. "Immediately below the Stormville limestone just described, there occurs a bed of water lime (2, p. 136-137) which seems to be quite persistent from the extreme eastern line of the district southwestward beyond the center of Monroe County, or at least as far as Stormville, from which locality the stratum in question was designated. It is seldom over 5 feet thick though occasionally attaining to 10 feet. The rock is usually of a pale-buff color, and breaks with the peculiar earthy fracture characteristic of hydraulic limestones; non-fossiliferous, although just under it millions of *Leperditia alta* are found.

"This bed is seen in the steep slope of the hill facing the Delaware River near Decker's Ferry, at the eastern line of Monroe, and at numerous localities from there on, southwestward to Stormville.

"The following analysis of specimens from several localities in Monroe show the composition of the Stormville cement bed as determined by Messrs. McCreath and Stinson:

	I	II	III	IV	V
$CaCO_3$	38.910	36.428	37.714	37.017	43.839
$MgCO_3$	23.724	17.481	25.351	26.410	29.664
Fe_2O_3	3.357	3.285	6.290	3.673	3.653
Al_2O_3	4.163	7.735		3.357	2.607
S	.065	......	.113	......	......
P	.038	......	.027	......	......
Insoluble residue	27.420	28.720	29.690	28.460	17.500

"The insoluble residue in each of the above after ignition gave the following:

	I	II	III	IV	V
SiO_2	24.150	23.940	24.850	23.970	12.630
Al_2O_3 + Fe_2O_3	2.500	2.740	2.450	2.740	2.040
CaO	0.220	0.110	0.260	0.000	0.120
MgO	0.404	0.183	0.490	0.227	0.144
Totals ...	27.274	26.973	28.050	27.027	15.934

I. Near Decker's Ferry, Middle Smithfield Tp., Monroe County.
II. Same locality, Middle Smithfield Tp., Monroe County.
III. Land of J. DeWitt, Middle Smithfield Tp., Monroe County.
IV. Land of J. DeWitt, Middle Smithfield Tp., Monroe County.
V. Stormville, Hamilton Tp., Monroe County.

"No attempt has ever been made to manufacture hydraulic cement from this bed so far as I could learn; but it would seem from the composition given above that portions of this stone might be selected which would make a very fair cement. At the locality where specimens III and IV were obtained, the bed is 10 feet thick, so that some of it would almost certainly make hydraulic cement."

The following notes on existing exposures give some indication of the character of the Helderberg limestones of the county.

Between the Delaware Water Gap and the sharp bend in Delaware River just below Bushkill, the Helderberg limestones outcrop along the south slope of the prominent ridge formed by the Oriskany sandstone. In places they are concealed by the alluvial debris of Delaware River; in other places the outcrops are high in the slope of the ridge and apt to be concealed by Oriskany sandstone talus. Almost opposite the lower end of Depew (Vancampan) Island there is a small old quarry showing thin-bedded limestones free from chert. An old lime kiln indicates the use made of the stone. Two other similar quarries were noted, one a short distance northeast of the Dimick's Ferry Road and the other a short distance southwest of the same road. About 2 miles east of Shawnee, a small quarry exposes about 5 feet of very fossiliferous cherty limestone with almost flat beds.

From Experiment Mills (North Water Gap) southwestward the Helderberg limestones are exposed in many places on the ridge forming the north side of Cherry Valley. This ridge is known as Godfrey Ridge between Experiment Mills and Stormville, and Cherry Ridge between Stormville and Saylorsburg. Along the N. Y. S. & W. Railroad at Experiment Mills, the Helderberg limestone is exposed for several hundred feet and also at several places along the wagon road. Always it is found on the hillside or even the hill top. On the southwest side of Brodhead Creek at the end of Godfrey Ridge there is a fairly large abandoned quarry. The exposure shows about 60 feet of thin-bedded, gray to dark-colored lime but becoming white on weathering, stone

of good quality with a general dip of about 20°NW. On the west face the strata are slightly folded. There are no lime kilns here, yet it seems probable that the stone quarried was burned.

West of this quarry no outcrops can be seen for several miles on account of the thick glacial deposits. The next exposures were noted about 2 miles south of Stroudsburg. From there to Stormville there are numerous outcrops both on the hillside and extending into the valley.

West of Stormville glacial debris covers the Helderberg as far as Bossardsville where, due to several minor folds, the limestones cover the tops of the hills and the regular southwesterly trend of the band is interrupted. More limestone has been quarried close to Bossardsville than in any other part of the county.

About one mile northeast of Bossardsville the Helderberg limestones were once quarried and burned at two places. The rock is gray, weathering white, and is in fairly thin beds. The beds dip to the north at angles of 25° to 40°. In the eastern opening there are several minor folds in the northward dipping beds.

Charles H. Heney for several years operated quarries on the north side of the road at Bossardsville and burned lime. The stone was dark blue with numerous thin bands. Some stone was said to have shown on analysis 85 to 90 per cent $CaCO_3$. In some quarries in this vicinity stone with 96 per cent $CaCO_3$ has been obtained. Although the strata were considerably crumpled the average strike was about N.54°E. and dip 42°NW. There were 6 kilns here and Mr. Heney produced as much as 10,000 bushels of lime annually which was sold to the farmers in that vicinity. On the south side of the road an old quarry was worked at one time rather extensively. There is considerable shaly material here.

The Bossardsville Limestone Co., Inc., worked a quarry about one-fourth mile southeast of Bossardsville for several years. Most of the material was crushed for highway purposes but for a time some of the higher grade was hauled to a cement plant near Nazareth. Some of the stone sent out compared favorably in composition with the Annville limestone of the Lebanon Valley, so largely used by those cement companies that require the admixture of some high grade limestone with the cement rock of their quarries. The stone shipped from Bossardsville had to be carefully selected as some shaly bands high in silica are interbedded with the purer gray to dark blue stone. There is no railroad connection with the quarry and the cost of truck transportation was too high to make a commercial success of the project. The property was tested by several prospect holes. Three of these holes gave the following results.

Hole No. 1 at Bossardsville

Nine ft. overburden.

	$CaCO_3$
From 9 to 15 feet	88.91
" 15 to 20 feet	83.97
" 20 to 25 feet	85.62
" 25 to 30 feet	90.21
" 30 to 35 feet	79.30
" 35 to 40 feet	63.14
" 40 to 45 feet	63.77
" 45 to 50 feet	83.09
" 50 to 55 feet	81.47
From 55 to 60 feet	78.21
" 60 to 65 feet	50.21
" 65 to 70 feet	53.65
" 70 to 75 feet	63.87
" 75 to 80 feet	78.03
" 80 to 85 feet	68.82
" 85 to 90 feet	45.34
" 90 to 95 feet	45.16
" 95 to 100 feet	43.53
" 100 to 105 feet " 105 to 110 feet	13.55

Analysis

	From 9 ft. to 25 ft.	From 25 ft. to 50 ft.	From 50 ft. to 75 ft.	From 75 ft. to 100 ft.
$CaCO_3$	85.81	75.51	65.30	56.35
$MgCO_3$	1.95	3.34	7.80	10.84
R_2O_3	3.26	6.00	8.14	8.96
SiO_2	8.28	14.86	18.04	22.74

Hole No. 2 at Bossardsville

Three feet overburden

	$CaCO_3$
From 3 to 10 feet	87.25
" 10 to 15 feet	93.50
" 15 to 20 feet	92.77
" 20 to 25 feet	86.53
" 25 to 30 feet	90.96
" 30 to 35 feet	87.43
" 35 to 40 feet	89.60
" 40 to 45 feet	71.53
" 45 to 50 feet	69.01
" 50 to 55 feet	68.65
" 55 to 60 feet	73.16
" 60 to 65 feet	75.68
" 65 to 70 feet	76.59
" 70 to 75 feet	79.11
" 75 to 81 feet	57.25
" 81 to 85 feet	79.66
" 85 to 91 feet	83.81
" 91 to 97 feet	54.55
" 97 to 115 feet	33.05
" 115 to 130 feet	22.58

Analysis

	From 3 to 25 feet	From 25 to 50 feet	From 50 to 75 feet	From 75 to 97 feet
$CaCO_3$	90.32	81.47	74.23	68.64
$MgCO_3$	1.71	2.51	2.81	5.00
R_2O_3	2.56	4.64	6.04	7.52
SiO_2	5.78	10.64	16.04	18.04

Hole No. 3 at Bossardsville

	$CaCO_3$
From 13 to 22 feet	89.42
" 22 to 28 feet	83.99
" 28 to 35 feet	71.52
" 35 to 49 feet	85.11
" 49 to 60 feet	88.53

Later the same property was prospected for black marble and some handsome polished specimens were prepared. If blocks of large size and good color can be obtained, it seems that it might become a commercial success for this purpose. The property must be more thoroughly investigated, however, before being recommended as a place to develop a black marble quarry.

Other quarries for lime have been worked in the Bossardsville region and all show some good stone but here and there interbedded with shaly strata.

From Bossardsville to Saylorsburg, the Helderberg is exposed in a few places near the top of Cherry Ridge but there has been little quarrying. On the south side of Chestnut Ridge from about 1½ to 3 miles southwest of Saylorsburg the Helderberg limestones have been worked in several places. In one of the quarries about 30 feet of blue-gray stone weathering to white with many calcite veins is exposed. The beds have a general steep slope to the south but in places are greatly folded and in certain parts of the quarry are practically vertical. The stone was used for lime and the calcite separated and discarded. The other quarries show similar material. Just above this

limestone lies the white clay that has been so extensively mined for the manufacture of white cement.

A short distance east of Bushkirk School, thin-bedded, somewhat shaly Helderberg limestone was once quarried and burned. The stone is gray, weathering to white. Some surfaces show fine wave marks. The beds dip about 10° north.

Just north of Aquashicola Creek about 1½ miles southeast of Kunkletown about 25 feet of stone are exposed in an old quarry worked for lime. The stone is in thin beds, 2 to 4 inches thick, and grayish blue. The beds dip northward about 20°.

About three-fourths mile south of Kunkletown some Helderberg limestone has recently been quarried in two different quarries where about 15 feet of stone was worked. The good strata were overlain by about 10 feet of shale.

MIDDLE DEVONIAN LIMESTONES

Onondaga limestones. The Onondaga (Upper Helderberg, Corniferous) limestone is well exposed in Monroe County and appears in a few places in Carbon County. It crops out in Monroe County from Delaware River near the mouth of Big Bushkill Creek westward at the base of the northern slope of Walpack Ridge to near East Stroudsburg where it disappears either through gradation into a sandstone or by the cover of glacial debris or both. It is exposed in several places along or near the main highway between Bushkill and a short distance northeast of East Stroudsburg. It is well exposed just south of East Stroudsburg. It appears in many places along McMichaels Creek Valley, first on the north side of the valley and then on the south side between Stroudsburg and Kellersville. The band then follows the valley of Lake Creek to Lake Poponoming at Saylorsburg. It was noted in a few places along the valley of Buckwha Creek between Saylorsburg and Frances School. Although not now exposed farther west, it apparently is present all along the valley of Buckwha Creek to the Carbon County line.

In Monroe County the width of the outcrop of the Onondaga strata is seldom more than one-fourth mile and generally less. The beds are about 200 feet thick near Stroudsburg and about 25 feet thick near Lehigh Gap.

White gives the following descriptions of the Onondaga limestone. (2, pp. 117, 118, 120). The Onondaga beds "consist of successive layers of dark gray limestone 1 to 10 feet thick, in which are embedded multitudes of black flint nodules one inch to one foot in diameter, having no regular shape but usually longer than thick, the greatest axis lying parallel with the bedding planes. On exposed surfaces the lime has been removed by solution while the nearly insoluble chert stands out in numerous black projections 6 to 8 inches high, giving the beds a most forbidding aspect, the sharp dagger-like points being the terror of bathers. No portion of the rock seems to be free from these flint nodules and in some parts of the stratum they make up nearly half of its material. They are not wholly silicious, but often contain a considerable quantity of lime, and then the nodules break up and decay by atmospheric influences; the lime being removed by solution leaves the silicious material in such a rotten or spongy condition that it also succumbs to the elements.

"The origin of these nodules by segregation is attested by the fact that they are often seen enclosing fossil shells, crinoids, etc.

"The following analysis by McCreath and Stinson shows the composition of an average specimen of these cherty nodules; locality, East Stroudsburg, Monroe County:

$CaCO_3$	20.267	99.148
$MgCO_3$	0.681	
$Al_2O_3 + Fe_2O_3$	0.640	
Insoluble residue	77.560	

The ignited "insoluble residue" gave

SiO_2	72.430	73.605
$Al_2O_3 + Fe_2O_3$	0.770	
CaO	0.210	
MgO	0.195	

"Of course there are many of the nodules that do not contain so much lime as this specimen, while others contain much more, if one may judge from the readiness with which they decompose when exposed to atmospheric influences.

"The limestone part or matrix which holds the flint nodules has the following composition as determined by McCreath and Stinson:

	I	II
$CaCO_3$	89.014	83.750
$MgCO_3$	0.915	1.157
$Al_2O_3 + Fe_2O_3$	0.380	0.480
S	0.056	0.025
P	0.012	0.070
Insoluble residue	9.860	14.470
Totals	100.237	99.952

I. From East Stroudsburg, Monroe County.
II. From land of H. H. Campbell, Smithfield, Monroe County.

"It has been burned for lime on several farms in Monroe County; but owing to the fact that the flint nodules were not separated from the matrix or pure limestone, the experiments in this direction have been far from satisfactory, since a very large amount of material always failed to slack, or else melted down into a silicious slag. The analysis given on a preceding page show the matrix of these nodules to be a very fair limestone for agricultural purposes, and one which should slack with no difficulty. If the farmers, when breaking the stone into small fragments for the kiln, would cast aside the flinty nodules, there would be no trouble in manufacturing large quantities of it into an excellent fertilizer and it would pay them to do this rather than haul their lime 5 or 10 miles further from the No. V (Helderberg) beds (as nearly all of them do), even if half of the Onondaga rock should be rejected in freeing it from the flint.

"Then too, some of the beds are much more cherty than others, the topmost layers usually containing more of the flint nodules than any other portion of the series; so that by a judicious selection of the quarry and proper care in casting aside the flint nodules, the farmers of eastern Monroe ought to make this the main source of the lime they use for agricultural purposes, at a great saving in cost compared with the price of the Lower Helderberg lime (No. VI) when hauled a distance of 5 miles or more."

Since the demand for crushed stone for highway construction has developed, some Onondaga limestone has been quarried for that purpose. The chert nodules even here are objectionable because of the difficulty in crushing them but in some places they are not sufficiently numerous to be serious. The largest quarrying operation in the Onondaga of Monroe County is that of Thomas P. Rogers located about 1¼ miles east of East Stroudsburg. Dr. Bradford Willard writes that "the rock which is being more extensively worked is a chert-free, sheared limestone. The cherty Onondaga is also present in the quarry, but is avoided as much as possible because of the difficulty experienced in drilling into it for blasting. They are running two shifts a day, with a maximum production of 300 tons of crushed stone daily." The stone is used for the roads. The quarry is a recently re-opened old quarry.

A small quarry in the Onondaga near Shoemaker was also once worked for crushed stone.

Hamilton limestone. Near the middle of the Hamilton formation there is a layer of shaly limestone or calcareous shale that was formerly called the Tully limestone. It is mainly a great mass of corals embedded in a shale matrix. It is about 30 feet thick and probably in no place sufficiently rich in calcareous material to be of value as a limestone.

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MONTGOMERY COUNTY

The limestone areas of Montgomery County although confined to the southern townships, nevertheless are of great economic importance as they are being worked on a large scale in several places. They underlie Whitemarsh Valley and that portion of Chester Valley which is within the county. In addition a small detached area of limestones of no economic importance occurs in Moreland Township in the vicinity of Bethayres.

Whitemarsh and Chester Valley have long been famous for their natural beauty, and their proximity to Philadelphia and suburban towns has caused them to become the site of elaborate country homes and golf clubs. There are seven extensive golf courses in the Whitemarsh Valley and one in that part of Chester Valley lying within Montgomery County. These pleasure grounds, country estates, and small towns have, in many cases, been established in such locations as to seriously interfere with the further development of the quarry industry of the county.

Utilization of Montgomery County limestones. Montgomery County has furnished a variety of limestones for many different uses. As in other counties of the State, the quarrying of limestone for burning for local farm use and for the construction of stone houses and barns marked the beginning of the utilization of the limestones of the county. The discovery of a fine grade of marble capable of taking a high polish was responsible for the development of an important branch of the quarry industry that has now passed away. Some very attractive marble obtained at Marble Hall, Plymouth Meeting, Conshohocken, King of Prussia, and other places has been extensively used in some of the finest of the old buildings of Philadelphia and elsewhere.

Probably the next development was the use of the local limestones, both those low and high in magnesia, for fluxing stone for the local iron furnaces. For this purpose almost any kind of limestone was accepted. From this beginning, however, there have grown up a number of plants where a superior grade of low silica dolomite is produced for shipment to steel plants. Similarly the lime industry has changed so that now the county produces from some plants having high-calcium stone a variety of lime of such character that it is largely used in chemical industries. The use of cement called for aggregate and several quarries are producing satisfactory crushed stone for this purpose. An unusual use for the Montgomery County low-silica dolomites is that of the extraction of the magnesia as described in an earlier part of this volume. This still continues although some Chester County stone has partially replaced stone formerly obtained from Montgomery County. In 1927 the first and only Portland cement plant of the county was built at West Conshohocken. The latest use of the limestones has been as a filler for asphalt and other articles. For this purpose a plant was recently built near West Conshohocken for mining and pulverizing some of the high grade marble.

CAMBRO-ORDOVICIAN LIMESTONES

The limestones of Montgomery County fall into four different classes. At the base, overlying the quartzites or quartz schists, designated as

"Chickies quartzite," is a series of dolomites aggregating several hundred feet in thickness. The complicated structure of the strata, the lack of continuous exposures, and the great amount of metamorphism by extreme compression and consequent heating which these rocks have undergone all combine to make the exact or even approximate determination of the thickness of any of the formations of the region almost impossible. The basal dolomites probably represent

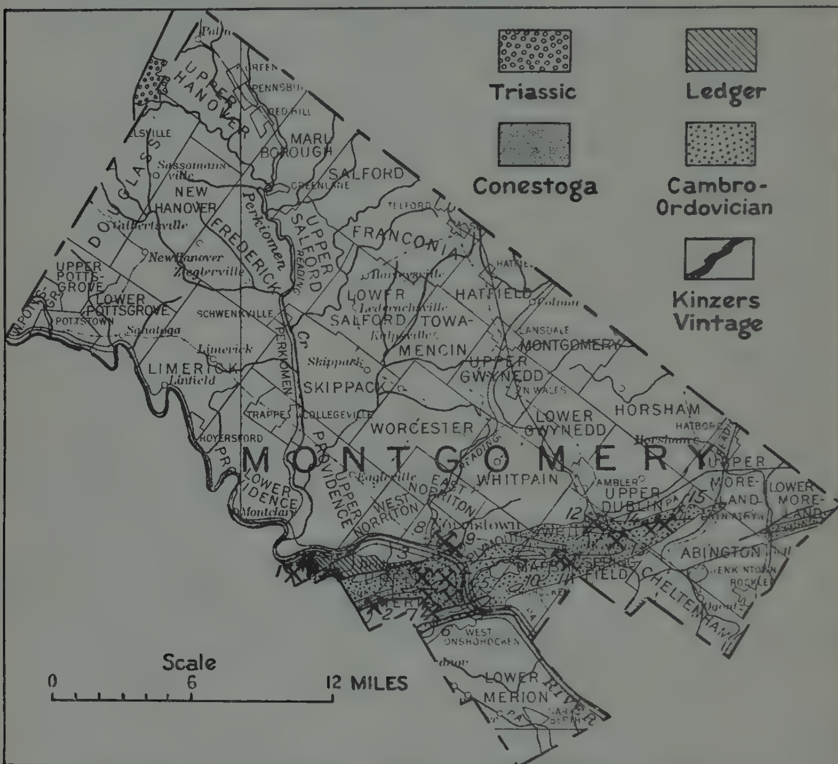

Fig. 26. Limestone areas in Montgomery County.

1. Ehret Magnesia Manufacturing Co. 2. Universal Atlas Cement Co. 3. Bethlehem Mines Corp. 4. The Warner Co. 5. Valley Forge Cement Co. 6. Thompson, Weinman and Co., Inc. 7. Lukens and Yerkes. 8. Mann Co. Yoch and Roberts. 9. Lukens and Yerkes. 10. Cox Limestone and Lime Products Corp. 11. G. and W. H. Corson. Blue Bell Lime Co. 12. Keasbey-Mattison Co. 13. F. Cairo and Son. 14. J. J. Cannon. 15. Merrill Margerum.

mainly the Ledger dolomite but perhaps the Elbrook and Conococheague groups as well. These are described in the Lancaster County portion of this volume. These dolomites are being or have been extensively worked in the quarries southwest of Port Kennedy, near Bridgeport, along the Plymouth Branch of the Reading Railroad, and near Whitemarsh and Fitzwatertown. The best grade of dolomite is a fine-grained, light buff-colored, dense stone that on fractured surface resembles a light-colored, compact cheese. This type of stone in some places contains even less than 1 per cent silica and over 40 per cent $MgCO_3$. Some specimens of rock have almost the same composition as the mineral dolomite. Gray, grayish-blue, dark bluish, or mottled

gray and blue varieties are also present in these dolomites, and they run lower in $MgCO_3$ and higher in silica. To get the best grade of dolomite means that careful investigations must be made and the good varieties separated from the poorer. In general, this vicinity furnishes some of the best dolomite produced in the State. It has been worked for fluxing stone, for stone for the extraction of magnesia, for magnesian lime of high grade, and for crushed stone.

Overlying the dolomite and in general occupying the central portion of Whitemarsh and Chester valleys, there is a thick band of interbedded dolomite and limestone. The two varieties occur in rather thin bands so that it is difficult to operate a quarry and keep the two apart. In a few places quarrying has been done in such a way as to produce a high magnesian stone from one part of the quarry and a low magnesian variety from another part. However, in doing this there is bound to be considerable admixture if the stone is not hand picked. Even if hand selected, it is difficult to obtain as good quality dolomite as can be secured from the underlying formation, or as good marble as can be secured from the overlying strata. Also in most cases, considerable silica is present in both kinds of stone. Fossils have been found which seem to indicate the Beekmantown age of the formation and these confirm a correlation based on the lithologic character of the beds and their stratigraphic relationships. Dr. F. Bascom (3, p. 5) has described the fossil occurrence in this county as follows:

"Fossils have been found in Chester Valley in somewhat ambiguous material. This material is a drusy geodiferous rock which seems to have originated through the replacement of calcareous material by silica. A mass of the rock is exposed just south of Bridgeport, near the Trenton branch of the Philadelphia Railroad.

"The material has not proved fossiliferous except at one locality, near Henderson station, where fragments resting on the surface of the ground have been found to contain gastropod and cephalopod forms.

"The following determinations were made by E. O. Ulrich, of the United States Geological Survey: *Raphistoma,* two species, *Maclurea, Lituites cyrtoceras.* These are Ordovician forms and indicate a horizon in the lower half, probably Beekmantown."

The stone from this formation (Beekmantown) has been mainly worked for crushed stone and for lime.

Overlying the Beekmantown is a more or less persistent band of marble which consists of coarsely crystalline gray marble, low in $MgCO_3$, interbedded with highly magnesian stone, much finer in texture and a great deal harder. Most of the marble produced in Montgomery County has come from this band. The marble varies from clear white to gray to mottled. Some specimens show fine banding of the white to grayish blue. Some portions are a very beautiful pink. The two places worked most extensively are at Marble Hall and at the old Schweyer quarry, half a mile southeast of King of Prussia. On a smaller scale, the same horizon has been worked for marble in a few other places.

At one time there was an important marble quarrying industry in the Chester and Whitemarsh valleys. Most of this probably came from Montgomery County, although several marble quarries have been worked in Chester County as well. Marble from this region was in great demand in Philadelphia and surrounding regions. It was used in the construction of Girard College, the U. S. Custom House in

Philadelphia, and other prominent buildings. The Washington sarcophagi at Mt. Vernon, Va., and the Pennsylvania marble blocks in the Washington monument in the District of Columbia are made of Chester Valley marble.

It is believed that the so-called "marble band" constitutes the basal part of the formation called Jacksonburg in the Lehigh Valley or Conestoga as it has been named in Lancaster and York counties.

The latest limestone formation in Montgomery County occupies the south part of the Whitemarsh and Chester valleys, bordering the South Valley Hills of mica schist west of Schuylkill River and the hills of Chickies quartzite east of Conshohocken. The writer believes that the mica schist bounding the south side of Chester Valley is of Ordovician age and is to be correlated with the Martinsburg formation of the Lehigh Valley. The most typical stone of this formation is what has been generally called a "micaceous limestone." It is a coarsely crystalline marble, low in magnesia but containing many thin partings of sericite (muscovite) mica along which it readily breaks. The side view of a broken piece of this stone appears to be a mica schist as the whole surface is covered with overlapping flakes of mica. On looking at the broken edge of a piece of stone, it seems to be a gray marble practically without impurities because the thin edges of the mica flakes are not readily seen. Lenses of high grade coarsely crystalline white marble and white to buff dolomite are present in places. In addition, there are some lenses of interbedded mica schist with practically no calcareous matter. The micaceous limestone with the lenses of marble, dolomite, and mica schist seems to represent the major (upper) part of the Jacksonburg formation of the Lehigh Valley where it has long been so extensively quarried for the manufacture of Portland cement. In Lancaster and York counties this assemblage of beds has been called the Conestoga formation. It is this stone that is being quarried and manufactured into Portland cement by the Valley Forge Cement Co. at West Conshohocken. In earlier times it was worked for lime, for flux, and for building stone.

Structure of the limestones of Chester and Whitemarsh Valleys. The structure of the limestones of the Chester and Whitemarsh valleys is complex as the strata have been greatly folded and also faulted. In general, however, they dip steeply to the southeast and strike parallel to the direction of the valleys. The older formations occupy the northern portions and dip to the southeast beneath successively younger strata. Minor and major folds and faults disturb this order considerably. In the micaceous limestone, there are numerous small folds involving only a few feet of strata so tightly compressed that except at the very crest or trough of the fold both sides are parallel. Folding of this kind renders it almost impossible to determine the true thickness of the various formations.

DESCRIPTION BY DISTRICTS

In the descriptions which follow it has not been deemed advisable to describe every quarry that has been worked. Those that are described will serve to furnish an idea of the different kinds of stone and uses. Anyone seeking a stone of definite chemical composition or physical character will find it necessary to do considerable field

work and probably will need to do some careful prospecting by trenching or drilling.

Port Kennedy Area. There has been rather extensive quarrying in the past in the vicinity of Port Kennedy but there is little prospect of much future activity in that section because a number of these quarries are now included within the recently enlarged Valley Forge State Park. One of the largest of these old quarries is in the southwest part of Port Kennedy. It was long worked for stone for lime production. Water fills most of the excavation. The stone quarried was dolomitic. This quarry is of considerable interest because it shows Triassic red shales and sandstones unconformably overlying the Cambrian dolomites. Also in this quarry a cave was broken into during quarry operations and a number of mammalian bones of Pleistocene age, some of which belong to species now extinct, were found in a deposit of cave earth.

The Ehret Magnesia Manufacturing Co. has a large quarry beside their plant about 1½ miles southwest of Port Kennedy. Here a high grade dolomite has been quarried for the extraction of magnesia by a process described in the earlier pages of this volume. The dolomite varies in color from blue to gray to white or light buff, but in composition is remarkably regular. The beds are massive, dip steeply to the south, but are badly jointed. The rock is dense and finely crystalline. The best stone contains well over 40 per cent $MgCO_3$. Three analyses of their stone are as follows. Nos. 1 and 2 are from the lowest level where the rock is fresh and No. 3 is from a new face in the south part of the quarry much nearer the surface.

Analyses of dolomite at Port Kennedy

	1	2	3
$CaCO_3$	54.96	55.67	54.11
$MgCO_3$	44.14	44.22	42.12
$Al_2O_3 + Fe_2O_3$	.55	.45	.35
Insoluble and SiO_2	.47	.25	3.00
Total	100.12	100.59	99.58

In working the quarry only the "one-man size" blocks, about 8 to 12 inches in diameter, are used in the magnesia plant, the smaller sizes being sold for road metal or flux. This is the most westerly working quarry of the high grade dolomite in Montgomery County. Other quarries in the same vicinity formerly worked for lime are all owned now by the Valley Forge Park Commission. It is the same band of stone that is being worked in the vicinity of Bridgeport and Plymouth Meeting. There are a number of other old quarries to the southwest, south and southeast of Port Kennedy once worked for lime burning. Some of these show a good grade of dolomite.

King of Prussia Area. About one-third mile southeast of the old King of Prussia Inn is a large quarry that has been worked at different times for marble but now belongs to the Universal Atlas Cement Co. which purchased it to obtain high calcite rock for shipment to some of its cement plants. It was once owned by H. E. Millard who worked it for fluxing stone. The quarry has been idle for several years. The quarry shows a band of high grade stone which yielded

beautiful coarse grained marble, white, gray, blue and mottled, as attractive as any of the ordinary marbles now on the market. It represents the best development of marble west of the Schuylkill River. The good grade marble is underlain and overlain by interbedded dolomite and high calcite marble. The beds dip to the southeast at angles varying from 47° to 65° with a strike averaging about N78°E. There are two openings, the one to the west much larger than the other. Both were worked to approximately the boundary of the property . The dip carries the marble band beneath the highway. About 25 years ago, the quarry was in operation with good equipment for cutting and polishing the marble but the project was not successful. The character of the stone is shown in the accompanying chart.

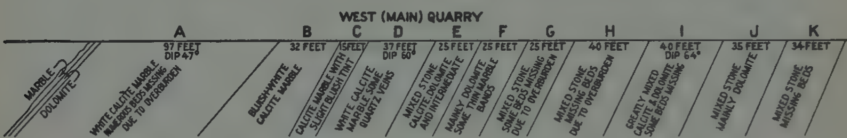

Fig. 27. Diagram of King of Prussia quarries.

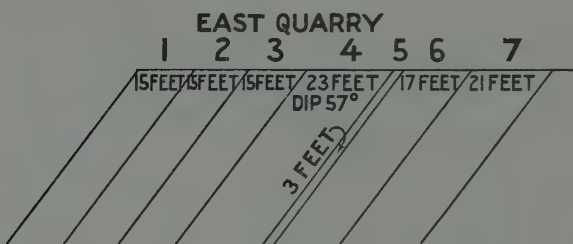

Fig. 27A. Diagram cross section

About 1¼ miles southeast of King of Prussia, Angelo George worked a small quarry in the micaceous limestone belt about 10 years ago for road metal and building stone. The heavy overburden of rotten rock was a serious obstacle so that the quarry was closed and the crusher dismantled.

Bridgeport-Shainline Area. High grade dolomite extends through the Shainline-Bridgeport region where there have been a number of extensive quarry operations in the past and where at present there are two large active quarries owned by The Warner Co. and the Bethlehem Mines Corporation. The overburden of residual clay is heavy in most places and deep clay pockets are common. The stone worked here, however, is such a good quality dolomite that the companies can afford to remove the clay.

The Warner Co. has long worked a quarry known as the McCoy quarry just south of the extreme east end of Bridgeport. For some time the Merion Lime and Stone Co. worked the same strata in an adjoining quarry. A few years ago The Warner Co. purchased the Merion Lime and Stone Co. and has since consolidated the Rambo and McCoy quarries into a single very large opening about 1200 feet long and over 500 feet wide. The depth worked has been about 60 feet but a new level is being worked in the old floor which is 50 feet

deeper. The strata are remarkably regular in dip although readings taken in different parts of the quarry show variations of several degrees. The average strike is almost due east-west and the average dip is about 45°S. In places there are shattered zones where earth movements have broken the massive rock into small angular fragments. These shattered zones vary from a few feet in width to nearly 20 feet. They cut across the beds vertically in certain places, elsewhere at an angle, and trend in various directions. Their presence cannot be predicted but they are not sufficiently numerous to be a serious disadvantage. Water has been able to enter these portions readily and the process of decomposition by solution has extended to considerable depths.

Three different kinds of stone are developed in the quarry. On a map these appear as three parallel bands. Practically the entire quarry operation is confined to the second band.

The lowest band of rocks exposed occupies the northern part of the property. These appear in the north wall of the main quarry. They are dolomites of fair quality, but being inferior to the overlying beds they are not used for the manufacture of high grade lime. Accordingly the quarry has not been continued northward into this type of rock. If there was a large quantity of this rock which could be quarried without interfering with the operation of the main quarry, one would be disposed to recommend the quarrying of this material for concrete aggregate. It would be entirely satisfactory except in spots where it has been unduly shattered and decomposed by ground waters.

The second band crossing the property is the one most extensively worked. It is the high grade dolomite band that furnishes the stone for the manufacture of lime. The big quarry now in operation (formerly the McCoy and Rambo quarries) was worked entirely across the band which at the surface is 520± feet wide. With a dip of 45° to the south the thickness is 368± feet.

The average analysis of 11 samples of stone collected in 1931 to be used for burning lime is as follows: SiO_2 0.48, $Al_2O_3 + Fe_2O_3$ 0.21, $CaCO_3$ 55.15, $MgCO_3$ 44.64.

The strata in this band consist mainly of compact crystalline gray to buff dolomite of good quality both for the manufacture of a low silica magnesia lime and for the extraction of magnesia. There are a few thin bands of bluish to mottled dolomite not well suited for high grade lime. It burns less readily and less evenly and makes a poorer lime and less lump. In the east part of the main quarry, three bands of this bluish stone were observed, ranging from 2 to 6 feet in thickness. A considerable amount of this stone in one place in the west part of the quarry was not removed thus making the west wall irregular.

Beneath the soil overburden percolating waters have removed considerable portions of the carbonates in the upper portions thus leaving the rock porous and easily crumbled in the hand. This rotten rock is unsuitable either for lime or crushed stone. Fortunately, it does not extend downward more than a few feet in most places.

South of the band of good dolomite there is a band that consists of interbedded dark (bluish) and light stone. The dark material is of the same quality as that described as occurring in thin layers in band

No. 2, but in this band it predominates so that it is inadvisable to attempt to use this stone for lime even though the light layers are of good quality. On the south wall of the large quarry west of the incline some of this material was shot down. The stone in this band is well adapted for crushed stone.

In the now idle Merion quarry of The Warner Co., located about one-fourth mile to the west, only the south portion of the band of good dolomite has been opened up. This was burned for lime by the former Merion Lime and Stone Co. During the World War, the quarry was advanced southward into the band of overlying mixed stone which was quarried and sold for flux.

Since 1925 the Bethlehem Mines Corporation (subsidiary to the Bethlehem Steel Co.) has been operating a dolomite quarry about half a mile southwest of Bridgeport, on a branch of the Reading Railroad. Previous to that time there had been a quarry here and some lime kilns nearby where the stone was burned. All of the stone in the quarry is high in magnesia. The color varies from white to buff to gray, bluish gray and mottled. An average analysis furnished by the Corporation is as follows: $CaCO_3$ 53.50, $MgCO_3$ 44.00, $Fe_2O_3 + Al_2O_3$ 1.25, SiO_2 1.25.

The beds which are fairly massive but greatly jointed vary in strike from N15°E. to N70°W. and in dip from 40°S to vertical. There are some faults in the quarry, but they are not of sufficient displacement to complicate quarry conditions. Along some of the fault planes the rock has been greatly shattered and occasional cavities are lined with quartz crystals. The quarry is about 1200 feet long, 500 feet wide, and 90 feet deep. The water pumped from the quarry is used to wash the stone. The overburden of stiff red clay containing some Triassic cobbles and boulders is heavy and in places runs down along joints or in solution pockets to a considerable depth. The operation is well equipped. The stone is loaded by electric shovels into trucks, hauled to the foot of an incline and there hoisted to a crushing, screening and washing plant. Lump and rice dolomite are made for the steel industry. The plant is equipped to make commercial washed crushed stone and sand. The new plant, erected in 1931, has an estimated capacity of 300,000 tons of dolomite for steel plants and an equal capacity of commercial stone. From 1925 to 1931 the quarry produced 349,000 tons.

Henderson-Swedeland Area. The Henderson-Swedeland area contains a number of quarries opened in the Beekmantown formation and the overlying marble band of the Conestoga (Jacksonburg) formation. Nearly all of them contain some good high calcite marble as well as dolomite. The Shainline quarry at Henderson Station, where some fossils have been found as described above, yielded some marble as well as stone for lime and flux. About half a mile south of Henderson Station are two old marble quarries, known as the Henderson quarries, where some attractive marble was quarried many years ago. The beds have steep dips and quarries in the narrow band of good stone quickly reached the depth where water interfered badly.

One of these old quarries was reopened a few years ago and is now operated by Thompson, Weinman & Co., Inc., to obtain stone for pulverizing for filler material and for whiting. The old marble

workings extended down from the surface on the main ledge to a depth of about 175 feet and in a second ledge not quite as deep. The marble was cut out by channeling machines and the two ledges worked along the strike for a considerable distance. The stone in this property consists of interbedded coarsely crystalline white to white and light blue banded or mottled marble in parallel beds interbedded with dark blue to black hard siliceous dolomite. The strata have a strike of approximately east-west and dip about 60°S. The largest and most southern bed worked varies from 20 to 25 feet in thickness. It is underlain by 30 feet of siliceous dolomite and then the second marble bed formerly worked is found. It is similar to the first marble band; but only 10 to 12 feet thick. These two marble beds are connected by a cross tunnel on the 200-foot level. This tunnel was extended to the north for the purpose of prospecting and after passing through 80 feet of dark colored dolomite a third parallel marble band, previously unknown, 8 to 10 feet in thickness was found. Further crosscutting may result in the discovery of additional suitable marble.

The present company has sunk an inclined shaft along the footwall of the principal ledge to a depth of 200 feet and is mining the stone by underground stoping. Considerable stone has been obtained from this ledge but working westward some of the stone has been found somewhat discolored and not adaptable for their purposes. The second ledge has been extended almost to the property lines and the third ledge is being developed. A new inclined shaft is under construction from the surface and has reached the depth of 290 feet. It is planned to extend it to 300 feet and there develop new levels in each of the three marble bands and by overhead stoping work up to the 200-foot level. At the 290-foot level a strong flow of water under 45 pounds pressure, struck in a drill hole, has delayed the work. Water in the 200-foot level issues from holes in the rocks under considerable pressure and 700 to 800 gallons per minute are being pumped. Undoubtedly the water problem will continue to be a serious one as the operation is located in a low place and in addition, due to earth movements, the rocks have been shattered and the water moves freely through the cavernous rocks from considerable distances. The deeper the mine is extended the more water is to be expected, gathered from a larger area. How successfully the water can be shut off by grouting has not yet been determined. The water which has flowed through the rocks has discolored the stone with iron rust (limonite) in several places, thus rendering it useless to the company.

The product of the mine is all pulverized to different degrees of fineness and sold for various uses. Three grades based on fineness are being made. What is called "Coarse," 88 to 98 per cent through 200-mesh screen, is sold for putty filling, caulking compounds, and paint. The "Fine, dry ground," 99½ per cent through 300-mesh screen, is used for paint products and rubber filler. The "Fine, wet ground," 100 per cent through 325-mesh screen, is used for linoleum printing and paints. The company can produce 40 tons per 24 hours of the wet ground grade and 72 tons of the dry ground grade.

Lukens & Yerkes have long worked a quarry about one-fourth mile southeast of Henderson Station. The quarry is about 400 feet long, 300 feet wide, and 90 feet deep to the lowest level which is now being developed. The output from this quarry was long used for fluxing

stone by local iron furnaces but in recent years has been used only as crushed stone. Some of the stone is mixed with asphalt at the plant for road use. The stone in the quarry is a mixture of high-grade, coarse-grained, white, gray and mottled, or banded white and light blue marble interbedded with dark blue to almost black dolomitic limestones and dense buff-colored, high-grade dolomite. By careful separation several grades of high quality stone might be produced. Many different analyses of stone might be obtained from this quarry. However, all kinds are crushed together for concrete and roadwork. The beds have a general east-west strike and an average dip of about 30° to 40°S. There are many variations with some pronounced folds in the middle and south part of the quarry. The red clay overburden is fairly heavy. The daily capacity of the plant is about 400 tons of crushed stone.

A few other quarries have been worked here in the past, including one formerly operated by the Alan Wood Iron and Steel Co. (now the Koppers Corporation). There is some high grade calcite marble in this quarry but interbedded with some dolomite. The clay overburden is heavy and there are numerous deep clay-filled solution pockets.

West Conshohocken Area. Just above West Conshohocken on the west side of Schuylkill River, stone has long been quarried for burning to lime and for building stone. The stone is the micaceous limestone with interbedded lenses of high calcite marble and dolomite of the upper portion of the Conestoga (Jacksonburg) formation. As a building stone, this product was desirable as the mica covered surfaces of the bedding planes and the gray marble layers that are shown in the broken ends of the blocks present an attractive appearance. In 1924 it was recognized that this material in certain places throughout the region was approximately of the correct chemical composition for the manufacture of Portland cement. An elaborate investigation of the character of the stone was carried on by diamond drilling and in 1927 the Valley Forge Cement Co.'s plant was built. Although most of the micaceous limestone of this valley is unfit for Portland cement by itself because the $CaCO_3$ content is too low or the $MgCO_3$ too high, this company has developed a large amount of stone of proper composition and is able to produce a good quality cement without bringing in any high grade limestone as do most of the cement companies of the Lehigh Valley. Before these investigations, the micaceous limestone was considered unsuitable for cement manufacture and had been so pronounced by several cement chemists. The physical character of the stone, due to the great metamorphism which it has suffered, was responsible for the failure to recognize its true character.

The detailed examination of the property of the Valley Forge Cement Co. has shown the presence of three different kinds of rock. These are (1) a soft, coarsely crystalline marble containing 45 to 50 per cent CaO, (2) a compact, fine grained dolomite stone analyzing 10 to 17 per cent MgO, and (3) a micaceous limestone that contains 35 to 40 per cent CaO and about 2.5 per cent MgO. Most of the material belongs to the last type.

The strata generally strike N.78°E. but with slight local variations and the dip is 75° to 90°SE.

For convenience the high lime, coarsely crystallized stone varying in color from white to gray to bluish gray has been designated as marble. Outcrops of marble in different places over the property contain

upwards of 90 per cent $CaCO_3$. In the core drilling many additional bands of the same grade of stone were encountered. These are interbedded with the micaceous limestone and also in some places closely associated with the high magnesian beds. It has not yet been shown definitely that there is a band of this marble sufficiently thick and continuous to be worked independently.

The great proportion of the stone on the property is low in magnesia. Some lenses and a few fairly thick continuous bands, as determined by the drilling, run fairly high in their magnesian content. Nowhere does the magnesia reach the theoretical composition of dolomite. For convenience all of the stone that contains upwards of 10 per cent MgO is designated as dolomite. The dolomite is dense, finely crystalline and bluish gray to light buff in color. It is much harder than the other varieties of stone. A few thin layers of the dolomite cause no trouble because they can be absorbed in the quarry product in which the great bulk of the material is low in magnesia.

The most abundant stone on the property is a type not hitherto recognized as suitable for the manufacture of Portland cement. It is a gray to bluish crystalline rock in which there are numerous extremely thin laminae or partings composed of mica. On breaking the stone, the flat sides of the rock are seen to be coated with overlapping flakes of mica to such an extent that it appears to be a mica schist. However, on looking at the broken edges the mica is scarcely apparent and the stone appears to be a grayish marble. The analysis of this stone shows it to be of about the same composition as the cement rock of the Lehigh district. So much more abundant is the micaceous limestone as compared with the other varieties that the marble and dolomite are little more than interbedded laminae.

The outcrop of the micaceous limestone is deeply weathered in many places and appears as brownish-yellow micaceous soil. It is the residual material after the $CaCO_3$ has been removed by solution. In a few places on the property this silt overburden is heavy but fortunately it is relatively thin in those areas where the best stone has been found. Naturally it extends downward in pockets as does the residual clay overburden in all limestone areas, but the removal of this material in quarrying has not been difficult nor expensive as compared with many limestone quarry operations.

One of the most pleasing results that has developed in the deepening of the quarry has been the improvement of the quality of the micaceous limestone with depth. This was indicated somewhat in the drilling records, but it was not expected that the increase in $CaCO_3$ downwards would be as great as the quarry operations have proved to be the case. Selecting at random the results of 18 holes drilled for blasting, the following averages were obtained:

Depth in feet	10-20	20-40	40-60	60-80
$CaCO_3$	76.7	77.2	79.6	82.6

The improvement in quality with depth is really impoverishment toward the surface by leaching. In places where the stone appears to the eye as solid and very little affected, very appreciable amounts of $CaCO_3$ may nevertheless have been removed by solution.

The Valley Forge Cement Co. has one of the most modern plants in the State. The wet process is used. The two 223-foot kilns have a daily

output of 3000 barrels. The plant is the nearest one to Philadelphia and most advantageously situated in that much of its market can be reached by truck.

Just to the north of the property of the Valley Forge Cement Co. the micaceous limestone was once worked extensively for lime burning, but this quarry was abandoned a number of years ago.

Mogee Area. Just southeast of Norristown, in the vicinity of Mogee Station, close to the north bank of Schuylkill River, there are two operations in close proximity. The Mann Co., Inc. (formerly the Mann Iron & Steel Co.) is operating in an old quarry that was once used for lime. The present product is entirely crushed stone. The rock now being quarried is a thin-bedded band of blue dolomitic limestone containing many gash veins. Beneath these strata is a more massive gray dolomitic stone that is more expensive to quarry. At the very top of the section in the old quarry, there are some Triassic red shales and sandstones. The beds strike N.87°W. and dip 36°SW.

Yoch and Roberts have a crushed stone quarry just east of the Mann quarry. For several years stone from this quarry was used for flux by the Alan Wood Iron and Steel Co. In the quarry there are several varieties of dolomitic limestone. They vary from blue to gray, and are of different grades with reference to hardness and manner in which they break. In some beds the stone breaks with a smooth fracture and appears to be of a gnarly character. A thin layer of Triassic red shales and sandstones caps the limestones, as in the Mann quarry. The dip and strike in the two quarries are also similar. An analysis of the stone in the Yoch and Roberts quarry made in 1925 by the Ehret Magnesia Co. is as follows: SiO_2, 1.65; $Fe_2O_3 + Al_2O_3$, 2.20; $CaCO_3$, 57.10; $MgCO_3$, 39.10.

Lukens and Yerkes operate a quarry about half a mile south of the Yoch and Roberts' quarry. The quarry is an old one and the stone was formerly used mainly for lime burning. Since the World War, the entire product has been sold as crushed stone. The quarry is about 800 feet long with the strike, about 350 feet wide at the widest place, and 90 feet high at highest point. The beds are mainly massive and dip 30° to 45°S or even slightly more. The stone is all highly magnesian but of different grades of purity. Some of the buff-colored dense stone is almost pure dolomite but some of the light to dark blue varieties probably contain considerable silica. A few interbedded shaly layers are so decomposed that the material crumbles readily. The red clay overburden in places is only about 4 feet thick but in other parts of the quarry is as much as 25 feet. Some clay has also worked downward in the open joints. In one place the rocks have been badly shattered and the cavities are lined with small quartz crystals. In this material there is considerable malachite and some small masses of chalcopyrite altering to cuprite and malachite. Some of the malachite shows finely developed small crystals. These copper minerals in limestone are not common in this section so the occurrence is of some mineralogic interest. The Triassic sediments that still exist only a short distance to the north and which may have originally extended over this quarry contain copper in a number of localities so that it is probable that they represent the source of the copper minerals observed here.

Conshohocken Area. No limestone quarries have been operated in the immediate vicinity of Conshohocken in recent years. Several were worked years ago on a large scale in the environs of the town and yielded stone for flux, lime, and building construction. One of the largest is close to Schuylkill River in the northwest part of the town. The stone is of the micaceous variety of the Conestoga formation. It was used largely for railway bridges, walls, and foundations. In the east part of town there are some large openings that yielded a good grade marble as well as micaceous stone for lime and for ordinary building construction. The clay overburden is very heavy in places. Also in the north part of Conshohocken there are some old quarries that produced some dolomite as well as high calcium stone. These also had a heavy overburden of sand and clay.

Marble Hall Area. At Marble Hall, about 3 miles northeast of Conshohocken, there are three abandoned marble quarries. In the Journal of the Franklin Institute of September 1867, Theodore D. Rand gives the following description of one of these quarries.

"About three-quarters of a mile west of Barren Hill, at Marble Hall, is the remarkable quarry of D. O. Hitner, Esq. This bed of marble, an altered Auroral or Trenton limestone, devoid of fossils, is nearly perpendicular, dipping S. 20°, E. 85°. The quarry itself is about sixty feet wide at the top, probably four hundred feet long and nearly or quite three hundred feet deep. The average thickness of the bed of white marble, which is of very fine quality, is about eight feet, but in one place it widens to twenty. Near the bottom of the quarry the bed of marble bends almost horizontally to the south-southeast, some fifteen or twenty feet, then again resumes its original direction. A few arches of the marble have been left to prevent the falling of the overhanging side of this vast and dangerous-looking chasm. Whatever the pleasure with which one may explore its depths, there is a great feeling of relief on safely emerging from it. A remarkable feature of this quarry is, that, although so deep and in limestone rock, very little water occurs; a comparatively small pump keeps it always dry enough for convenient quarrying.

"Except the marble, this quarry produces little of note to the mineralogist. Some twenty years ago a mass was detached and the usual hoisting apparatus applied, which gave way. It was repaired but again the same result followed, when it was found that the mass was far heavier than the marble which they had supposed it to be, and from which it could not be told by the eye—it was sulphate of baryta or heavy spar, the specific gravity of which (4.3 to 4.7) is nearly double that of marble (2.5 to 2.7), so that while a cubic yard of the latter would weigh about 4200 pounds, the same bulk of the former would weigh over 7500."

It seems rather improbable that barite such as described by Rand actually was found in these quarries. There is no present evidence to support the statement that it occurs there in large masses, or even in small quantities. Mr. Rand was an able mineralogist so one wonders whether his statement was not based on hearsay evidence of untrained observers.

Of the three marble quarries at this place, two of them are now included within a golf course. There are a number of exposures of fine appearing marble in the surrounding territory.

One of the Marble Hall quarries yielded a dark blue marble of good quality. If one may judge from the pile of refuse about the pits there was not much loss. The stone in the blue marble quarry shows some close folding.

Although Marble Hall, Henderson, and King of Prussia are the most prominent localities where marble has been quarried in the valley it is highly probable that other places exist where equally desirable marbles might be obtained. At present it is generally believed that the region cannot successfully compete with the marble districts of other States.

Additional information of interest in regard to the marble quarries of Montgomery County is given in Rogers' "Geology of Pennsylvania," (1, p. 215) based on information obtained in 1853.

"The quarrying of marble in this district was commenced about 75 years ago, by Daniel Hitner. For the last 15 to 16 years the average quantity sent from the quarries of Marble Hall, owned and wrought by the present proprietor, Daniel O. Hitner, has been about 25,000 cubic feet.

"The belt of marble is nearly three-fourths of a mile wide. Marble Hall, on the Perkiomen Turnpike, is the easternmost point at which good building-marble is wrought, though the belt is known to continue further. It extends thence to the Schuylkill nearly to the Chester County line.

"The largest quarry of all is that of Marble Hall; here the strata dip to S. 20°E. about 85°, presenting in one or two places a flatter inclination. This quarry is not less than some 400 feet in length, and at the top is 60 or 70 feet wide. The greatest depth to which the quarry has been sunk is 265 feet. At this depth were procured the blocks of beautiful white marble sent by direction of the State of Pennsylvania, and by the City of Philadelphia, to the great monument at Washington. At this depth the stratum of white marble, for which this quarry is chiefly wrought, has a thickness of 5 feet; but the usual thickness of this bed of pure white stone is 8 feet, that of the pure and clouded white together being generally about 20 feet.

"Mr. Hitner has quarried blocks 6 feet in thickness, though the general thickness of the blocks readily procurable does not exceed 2½ feet.

"The only saccharoidal or statuary marble in this or any of the quarries, is found here at a depth of 120 feet, in a layer of only 6 inches in thickness. It is of a yellowish white color and remarkable evenness of grain.

"The white marble is used for monuments, and for the finer architectural purposes. It now sells for about one dollar per cubic foot.

"To the south of the large quarry of Marble Hall, which, besides the white marble, yields much beautiful clouded or shaded stone, there is a quarry of blue and black marble, distant about 300 yards. This is owned by Mr. Lentz, but now wrought by Daniel O. Hitner. This blue and black marble now sells for about 40 cents per cubic foot. It is used chiefly for fronts of buildings, for monument bases, &c. The thickness of the good blue marble in this quarry is 22 feet, and that of the black variety 8 feet.

"Besides these quarries in the vicinity of Marble Hall, there are others about three-fourths of a mile north from Spring Mill; one set owned by Robert T. Potts, another adjoining his by Mr. Peter Fritz.

The marble of Potts' Quarry is chiefly of the clouded variety, besides a little white and some plain blue. The annual yield of this quarry is about 12,000 cubic feet.

"The quarry owned by Fritz is at present but little wrought.

"Next in position to the westward, but still seated in the same belt, are two quarries westward of the Schuylkill; these are Henderson's and Brook's, in Upper Merion Township.

"Henderson's, the nearest to the Schuylkill, affords a plain blue marble, besides a little white. Both of these quarries are wrought at present to only a moderate extent."

"The blue mottled limestone or marble of Whitemarsh, occurring at the quarries not more than three-fourths of a mile north of the northern limit of the Primal Strata, is evidently on the south side of the trough, or folded synclinal axis of the district. This is further proved by its great steepness of dip, about 80°. It is, moreover, of the maximum degree of metamorphism or crystallisation; contains talcose or micaceous laminae, and crystals of sulphuret of iron, &c.

"*Strontia.* Near Mr. Hitner's House, Marble Hall, there occurs a thin bed of very ponderous rock, resembling closely a white crystalline marble. It contains, however, but a moderate proportion of carbonate of lime, and consists chiefly of the carbonate of strontia."

Plymouth Meeting Area. One of the areas of high grade dolomite in the county extends as a continuous east-west band along the Trenton Cutoff of the Pennsylvania R. R. just to the north of Plymouth Meeting. It appears from beneath the cover of Triassic red sandstones and shales about a mile northwest of Plymouth Meeting and extends to about one-quarter mile east of Williams where it turns back to the west in a loop that carries it just north of Cold Point and Hickorytown. It then turns eastward in another east-west band that passes through Whitemarsh, Camp Hill, Fitzwatertown and eastward. The loops in this continuous band of dolomite are due to the way in which the band and associated strata have been folded and later eroded.

In the vicinity of Plymouth Meeting a number of quarries have been opened, most of which have long been abandoned. In the same section there are some old limonite iron ore pits. The chief reason for abandoning the quarries has been the presence of certain impure beds high in silica, alumina or iron. Also the overburden has been excessive in places.

Half a mile west of Plymouth Meeting is the formerly worked quarry and plant of the Philip Carey Manufacturing Co. The rock quarried was a high grade dolomite that contains over 40 per cent magnesium carbonate, 0.75 to 1.50 per cent silica, alumina, and iron oxide, the balance calcium carbonate. The stone was used for the extraction of magnesium carbonate, the process of which has been described in an earlier part of this report. The best stone is about 60 feet thick and is a gray to dove colored, compact, brittle stone. Another good variety is distinctly mottled. A blue stone underlying the best beds was also utilized except where it contained less than 40 per cent of magnesium carbonate. Only blocks from 8 to 12 inches in diameter were used for magnesia. The smaller sizes were sold for concrete and road ballast. At present all the stone used is being purchased from the Cedar Hollow plant of The Warner Co. A typical analysis of the stone

from Cedar Hollow used by Philip Carey Manufacturing Co. is as follows: Silicate .70, R_2O_3 .40, $CaCO_3$ 55.15, $MgCO_3$ 43.75.

Just north of Plymouth Meeting, some quarries show good dolomite rock but these have not been worked for many years and the lime kilns are in ruins.

Going eastward, the first operating quarry is that of the Cox Limestone and Lime Products Corporation, located about 1¼ miles east of Plymouth Meeting. The quarry shows different varieties of stone, the best being a light colored dense dolomite. Some of the other stone is much darker. Part of the stone is greatly shattered. Red clay overburden, clay pockets and a great deal of water have been serious obstacles in the quarry operations. The company burns lime and sells crushed stone.

Just east of the Cox quarry, the Johns-Manville Co. opened a quarry to obtain dolomite for the extraction of magnesia but did not work it long. Instead, the company buys the dolomite needed from other producers.

The E. J. Lavino Co. worked a quarry in this band also but it is now abandoned. A cover of red clay about 15 feet thick was used to make brick in a nearby plant. The stone quarried was fairly uniform and of good quality, although there was a band of dark blue stone of poorer grade. The rock was badly shattered as is so common in the dolomite of this area.

The most extensive quarry operation in this area is that of G. and W. H. Corson, who claim to be the oldest lime manufacturers in America. The stone is all dolomitic but varies somewhat in character in different ledges. The best grade dolomite is a light cream-colored dense stone that analyzes as follows: SiO_2 .80, Fe_2O_3 .31, Al_2O_3 .49, $CaCO_3$ 56.46, $MgCO_3$ 41.62.

Beside this best stone there are some bluish and mottled varieties containing more silica. In a few places there are some thin shale partings. The quarry is about 500 feet long parallel to the strike, and 360 feet wide. The area was worked over in a bench producing a face about 40 to 45 feet in height and is now being deepened by a second cut of 40 feet. It is believed that even a third cut of 40 feet can be made. The beds dip to the southeast at an angle averaging about 45°. The strike is about N.75°E. The beds range in thickness from 6 to 40 inches. In places the rock is badly shattered so that a large quantity of small size stone is obtained in quarrying. At one time the clay overburden was used in the manufacture of brick.

The stone from the Corson quarry is used mainly for lime, part of which is marketed as lump lime and part is hydrated. A stucco plant close to the property obtains all its lime from this company. A smaller part of the best quality stone is sold for the extraction of magnesia. The small stone obtained in quarrying and crushing is sold for crushed stone. The amount sold for extraction of magnesia is relatively small. Ordinarily about 60 per cent is used for lime and 40 per cent sold as crushed stone.

The Blue Bell Lime Co. operates a quarry a short distance east of the Corson quarry. There are two openings, one on either side of the Reading Railroad but only the one on the north side was being worked in 1931. Many years ago these quarries were operated for lime and for stone for the extraction of magnesia. The present plant was

erected in 1922. The stone is similar to that in the Corson quarry, although the quarry is not nearly as large and consequently fewer strata are exposed. Part of the raw stone is sold for flux, for the extraction of magnesia, for crushed stone and plans were being made to produce pulverized stone for agricultural use and for asphalt filler. Part of the stone is burned and sold either as lump lime or hydrated lime.

In the band of dolomite that lies just north of the ridge of quartzite which underlies Cold Point and Hickorytown there are no working quarries. One quarry that lies less than half a mile almost directly north of the Corson quarry exposes some good dolomite There are also two old quarries along the roadside about three-fourths mile northwest of the Corson quarry.

Whitemarsh Area. There are some old quarries in the band of good dolomite a short distance west of Whitemarsh. The only operating quarry in this area is along the Bethlehem Pike at Whitemarsh extensively worked by the Keasbey-Mattison Co. to obtain dolomite for extraction of magnesia in their plant at Ambler. The stone is hauled there by truck. The smaller sizes resulting from crushing are sold as road metal or are thrown into abandoned portion of the quarry with the soil and dirt as waste for filling. Three kinds of stone can be readily distinguished in the quarry. The best is a light buff dense (cheese-like) stone such as appears in other quarries in the dolomite band, although in general somewhat coarser here. Another variety is whiter and somewhat lower in its $MgCO_3$ content. The poorest is a bluish to mottled stone, called "bastard" stone, less desirable because much higher in silica. No attempt is made to separate the different grades of stone. The stone is so highly jointed that in places it is difficult to recognize the bedding planes. The dip varies from 20° to 30°SW. The quarry is about 450 feet long, 250 feet wide, and 50 feet deep. The highway on the west side and a high tension power line on the south limit the extension of the quarry in those directions. A fine spring in the bottom of the quarry yielding 650 gallons per minute, more in wet weather, furnishes water that is sold to two water companies in the region.

Oreland-Fitzwatertown Area. In the vicinity of Oreland and Fitzwatertown there are a number of dolomite quarries where lime was once burned. Several of these now lie within some of the golf courses of the section and are no longer worked.

The most active quarry in recent years is that of F. Cairo and Son, located along the Bethlehem Branch of the Reading Railroad in the northwest part of Oreland. Although this quarry is within the dolomite belt, the stone is of poorer quality for lime, flux or other purposes for which high grade dolomite is used than is that worked in the quarries just described. It is satisfactory for crushed stone for which use all of the production is employed. The quarry is an old one and is now about 600 feet long, 400 feet wide, and 50 feet deep. The beds dip about 40°S. The overburden of clay over most of the quarry is less than 5 feet deep but in one portion 30 feet of clay was removed. The stone varies in color from light gray to bluish gray. The beds are mainly massive, ranging in thickness from 8 inches to 2 feet. The capacity of the quarry is said to be 200 tons. The stone has been sold

for the township and county roads. The location of the quarry between the railroad, highway, golf club and creek renders extension much further in any direction impossible.

About one-fourth mile northeast of Fitzwatertown, J. J. Cannon operates a small quarry to obtain dolomite for burning lime. The stone is a fair grade, finely crystalline, dense, buff-colored dolomite which is said to have shown on analysis 55.05 per cent $CaCO_3$, 44.12 MgCOs, and 1.10 insoluble material. It is improbable that the run of quarry is as good as this, however. The quarry is about 250 feet long, 125 feet wide, and 30 to 35 feet deep. The overburden averages about 3½ feet. There are four kilns on the property. The lime is sold for farm use and for building construction. At one time a large quarry was worked at the road junction a short distance to the east of the present quarry.

About a mile east of Fitzwatertown is a small quarry belonging to Merrill Margerum, last worked in 1929 for crushed stone. Some building stone was also obtained here at times. This quarry shows a variety of stone, little good grade material in sight. Part of it is schistose and badly weathered. It is doubtful whether any good dolomite is to be found east of this place, although the band of limestone extends about 2⅓ miles farther east, a short distance beyond Rubicam.

In a number of other places in the Whitemarsh Valley, there are small abandoned quarries most of which were worked many years ago for building stone or to get stone to burn for agricultural lime . The stone is in places a mixture of dolomite and low magnesian limestone, and elsewhere micaceous limestone with occasional marble lenses. These quarries now have little economic value as sources of stone for any purpose.

Analyses of Cambro-Ordovician limestone

	1	2	3	4	5	6	7	8
$CaCO_3$	55.62	55.80	58.29	55.72	55.56	56.19	52.98	55.78
$MgCO_3$	43.10	41.22	37.93	40.96	42.07	41.03	37.30	40.03
Al_2O_3 Fe_2O_3	0.63	1.83	2.04	1.80	0.61	1.59	3.96	2.05
SiO_2	0.90	1.19	1.71	1.48	1.72	1.12	5.72	2.11

	9	10	11	12	13	14	15
$CaCO_3$	55.23	56.32	55.00	55.03	76.02	86.10	53.89
$MgCO_3$	43.22	41.95	43.19	38.50	18.17	11.86	42.72
Al_2O_3 Fe_2O_3	0.92	0.96	1.54	4.09	3.23	0.68	1.24
SiO_2	0.65	0.75	0.41	2.36	2.52	1.33	2.14

1. Quarry of Blue Bell Lime Co., Williams. Analysis of 2 cars shipped Bethlehem Steel Co.
2. Quarry of G. & W. H. Corson, Williams.
3. Quarry of Cox Lime and Stone Co. 1 mile east of Plymouth Meeting.
4. Quarry of Joseph Leedom, Plymouth Meeting.
5. Quarry of Philip Carey Mfg. Co., ½ mile west of Plymouth Meeting.
6. Quarry of E. J. Lavino & Co., 1 mile west of Plymouth Meeting.
7. Quarry of Deer Crushed Stone Co., ½ mile north of Ivy Rock.
8. Quarry of Lukens & Yerkes, Mogee.
9. Rambo quarry of Merion Lime and Stone Co., Bridgeport. Analysis of 22 cars shipped to Bethlehem Steel Co. (Quarry now consolidated with McCoy quarry of The Warner Co.)
10. Merion quarry of Merion Lime and Stone Co., Bridgeport.
11. Quarry of Pennsylvania Lime Products Co., Shainline.
12. Quarry of Norristown City Brick Co., Shainline.
13. Quarry of Lukens & Yerkes, ¼ mile S. E. of Henderson.
14. Quarry of Universal Atlas Cement Co., ½ mile S. E. of King of Prussia.
15. Quarry of Erwin Stone Co., Port Kennedy.

Analyses made by Bethlehem Steel Co.

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Pit and Quarry

4. Old Pennsylvania Marble Quarry now operated as a Whiting Mine, by R. W. Stone, Vol. 18, No. 12, pp. 59-61, Sept. 11, 1929.

MONTOUR COUNTY

Montour County is well supplied with limestones as they outcrop in all the townships with the exception of Anthony, West Hemlock, and Mayberry. In West Hemlock, a band of limestones would outcrop except for the deep cover of surficial hillside debris.

All of the limestones of the county of any consequence belong to the Helderberg (including Tonoloway) although some are also present in the Salina (?) and Tully series.

When the Clinton iron ores were being mined in this section, the limestones were quarried for flux in a number of places. They were also used more largely for burning for agricultural lime in former years than now. The principal usage at present is for crushed stone for the highways and concrete structures.

HELDERBERG LIMESTONES

The Helderberg (including Tonoloway) limestones outcrop in rather narrow bands running approximately east and west. The southern one extends from Danville eastward through Frogtown, Ridgeville, and Grovania into Columbia County. The next band northward parallels Montour Ridge, enters from Northumberland County and passes through Mooresburg, just north of Mausdale and eastward into Columbia County. These two constitute the remnants of an anticlinal fold in which the limestone over the arch has been removed by erosion.

Another anticlinal fold with the two limbs uniting in the vicinity of Washingtonville has the southern band forming Limestone Ridge between Limestone and Liberty townships and the northern one extending from Washingtonville through California and into Northumberland County.

Within these areas of outcrop, the Helderberg limestones have been worked in many places but especially in the vicinity of Grovania, Mausdale, and Washingtonville.

As in other counties in central Pennsylvania, the Helderberg of Montour County contains some high grade, low magnesian limestone that is suitable for the manufacture of high quality lime or for flux. It is interbedded with siliceous and argillaceous limestones, of much less value. Some beds fairly high in magnesia are also commonly present. When quarried on a small scale and sorted by hand the different kinds can be separated and used alone for the purposes for which they are best adaptable. On a large scale with steam shovels it would be difficult to work a quarry profitably if stone of uniform composition were demanded. For crushed stone all except the most shaly strata are acceptable.

DESCRIPTION BY DISTRICTS

Grovania Area. At Grovania, almost on the Montour-Columbia county line, is an old quarry that was described in detail by I. C. White in 1883. (2) This is known as the Grove quarry as it was long worked by Grove Brothers. It now belongs to Alonzo Mauser who has worked it in a small way for stone for a number of years. It now is leased by J. A. Savage, who works it for crushed stone. Mr. Mauser still gets out a little stone for burning. It has not been worked

continuously since its opening, which was probably long before 1883, but has been in operation in recent years to supply a good grade of stone for lime burning and a thin-bedded and harder siliceous stone for crushing for road building. Both varieties of stone are satisfactory for crushed stone. The quarry, which is located near the top of a small ridge with beds dipping steeply to the south, is drained by a tunnel that was driven through the overlying Marcellus shales and Oriskany sandstones into the Helderberg limestones. The quarry has been worked in an east-west direction along the strike about 1400 feet.

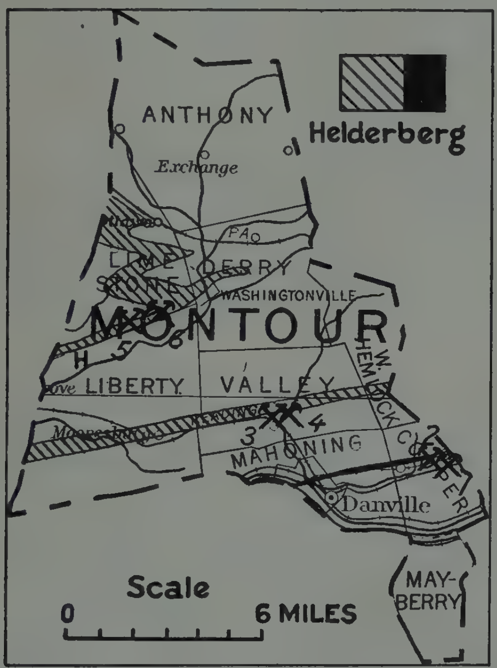

Fig. 28. Limestone areas in Montour County.

1. Alonzo Mauser. 2. John F. Sommers. 3. Mausdale Quarry Co. 4. D. J. Crossley. 5. Hagenbuch and Wagner. 6. Harvey R. Shultz.

The following abbreviated section by Reeside (3, pp. 224-225) in which the various fossils found in each band are omitted, shows well the character of the beds present in the quarry.

Section at Grovania

	Thickness in feet
Limestones and shales of undetermined age, but probably New Scotland and Oriskany, cut by tunnel	110
Helderberg limestone:	
Coeymans limestone member:	
Sandstone, coarse (grains $\frac{1}{16}$ to $\frac{1}{8}$ inch in diameter), white; base filled with crinoid stems and other fossils; contains some chert ..	3.0
Keyser limestone member:	
Limestone, irregular, crinoidal, dark blue	1.6
Limestone, compact, light, blue, heavy bedded; conchoidal fracture	5.5
Limestone, laminated, light gray to yellowish, platy. Has some solid 6-inch layers of light-gray rock, but for the most part is rather shaly. Barren of fossils	36.4
Limestone; a peculiar pebbly stromatoporoid makes up whole of rock	3.0

	Thickness in feet
Keyser limestone member—Continued.	
Limestone, blue, pure, with many transverse calcite seams; massive and somewhat nodular; composed almost entirely of stromatoporoids; has ½-inch layer of shale at top	3.4
Shale, yellow	.2
Limestone, composed almost entirely of stromatoporoids	5.6
Shale, blue-black, with one or two limestone layers	4.6
Limestone, crystalline, blue, pure	1.3
Limestone, crystalline, blue, pure, many transverse calcite seams	.8
Limestone, crystalline, blue, pure, massive; weathers thin bedded; has much black shale. Stromatoporoids throughout	8.0
Limestone, crystalline, blue, pure, massive; numerous transverse thin calcite seams; weathers thin bedded	10.0
Limestone, heavy bedded, light gray; has great masses of vein calcite	6.0
Limestone, crinoidal, relatively impure	.6
Limestone, light gray, nodular; much shalier than the beds beneath; weathers easily; "Bastard" limestone of the quarrymen	23.6
Shale, irregular	.3
Limestone, irregularly bedded, somewhat nodular, dark gray; courses often separated by shale laminae	11.6
Total thickness of Keyser	122.5
Tonoloway limestone:	
Limestone, dark gray, pure; conchoidal fracture; many transverse calcite seams; when unweathered is a massive unit though 1-inch bedding is shown in the upper part and 6-inch bedding near the base; it is not nodular or platy; shows a persistent thin shaly layer	12.0
Limestone, fissile, platy, dark gray; joints have yellow discolored borders	10.0
Limestone, fissile, platy, much weathered	6.0
Limestone, solid, dark gray, banded in parts	6.6
Limestone, fissile, platy, much weathered, yellow; fresh surface is dark gray	4.3
Concealed	
Total thickness of Tonoloway	38.9

About half a mile west of Grovania, John F. Sommers is working in the same ridge to obtain stone for burning. He works a thickness of about 25 feet of thin-bedded blue limestone with shaly layers both below and above. The strata dip about 45°SE. The quarry is a long narrow opening along the strike. Thin black shale partings about an inch apart occur in the stone used. The overburden of clay and rotten rock is variable but in general sufficiently thick to be decidedly objectionable. Two of the 3 kilns were in use in 1929.

Mausdale Area. For many years the Helderberg limestone has been worked in the vicinity of Mausdale and much stone has been removed from this section for flux, lime, and more recently for concrete work and road metal.

In 1929 the principal work was being done by the Mausdale Quarry Co. (William K. Savage and Son) who had leased the old Maus and Bright quarries and were crushing stone for the State highway between Danville and Milton. The company was paying a royalty of 4 cents per ton in the Maus quarry and 5 cents per ton in the Bright quarry. In the Bright quarry there was an exposure of 27 feet of hard gray to blue limestone containing many small calcite veins. This good stone is overlain by much shaly material that is worthless. A fault that cuts through the quarry also interferes somewhat.

In the Maus quarry, the layer of massive good stone is overlain by about 35 feet of shaly material. There are also some bad clay pockets where the limestone comes to the surface. The beds strike N78°E. and dip 33°NW. There are a few thin shaly partings within the ledge of good stone. Both of these quarries were at one time worked to supply stone for burning lime.

In the same band but a short distance to the east D. J. Crossley has burned lime in recent years. After removing a small quantity of overburden, a pure limestone was uncovered. The beds are about two inches thick and make up a total of about six feet. Under this thin material a massive blue gray limestone occurs, full of calcite veins. Many clay seams which average about three inches thick seem to be regularly alternated with the limestone. The grayish blue limestone is by far the best quarry rock in the locality. It has very little apparent variation in quality and structure. The clay seams often termina e in a shaly and slaty formation which is splintery and fragile. This quarry is owned by William McMahon, and was formerly operated by Charles Cook. It has produced 1200 to 1400 bushels of lime per week under the Crossly management.

The Russell quarry is across the ridge, and was formerly operated by the Philadelphia & Reading Coal & Iron Company to supply their Danville furnaces. Here the chief formation is the Tonoloway which is about 70 feet thick. The chief bed, although inaccessible for close study, showed the platy appearance of the Tonoloway and was directly beneath the Stromatopora bed of the Keyser. The "bastard" limestone overlies the Stromatopora bed, and in this quarry is approximately 20 feet thick. The strike of the rocks here is practically the east-west strike noticed in many quarries. The dip is 35°S. The quarry was operated along the line of strike. The material was used chiefly for lime.

Another locality in the same band is the Strickler quarry in the southeastern part of Liberty Township. This quarry is partially in the Tonoloway formation, as can be easily recognized by the thin and flaggy aspect of the beds and the overlying massive Stromatopora bed of the Keyser.

Washingtonville Area. The principal limestone operations in the Washingtonville area are in Limestone Ridge, that extends from the borough of Washingtonville westward and slightly south to the county line. In this band a great many quarries have been worked to supply the vicinity with agricultural lime. Old lime kilns are in evidence in several places. In recent years some lime has been burned but there seems to be little profit and the amount of lime produced annually is small.

In 1929 the principal working quarry in the region was that operated by Percy Hagenbuch and Harry Wagner, located about 1½ miles southeast of Limestoneville. Hagenbuch was taking out stone to burn for agricultural lime and Wagner was producing crushed stone for road use. The quarry is opened in the nose of the hill. The quarry face is about 50 feet high. The lowest stone exposed in the quarry, about 20 feet in thickness, is a massively bedded blue stone that breaks readily, above which is interbedded shale and limestone, largely waste. The beds strike N70°E. and dip 18°SE.

Farther east in Limestone Ridge there are a number of quarries all of which were idle in 1929 with the exception of the Schultz quarry.

The largest quarry is the one operated by Alex Billmeyer. It is situated along the north side of Limestone Ridge formed by the southern flank of the Milton major axis. Here the limestone beds are from one to three inches thick and are quite shaly. These thin beds are overlain by a somewhat shaly and sandy soil approximately

four feet deep. Below this sandy and shaly limestone the more massive limestones occur, and here the thickness of the individual beds averages six inches. The total thickness of the massive limestones is about 35 feet and the strike is N75°E. and the dip, 18°SE.

Five kilns on the property were used only as the farming community demanded lime. Practically all the limestone quarried in this area is burned.

The Umpstead quarry is directly opposite the Billmeyer working and is in practically the same beds. It is not as large and supplies three small kilns.

The Harvey R. Shultz (formerly Coleman) quarry is in a narrow valley due east of the other operations, and supplies one kiln. This quarry has been in operation for only a few years but the opening of the others dates back to 1866. The quarry face is 25 feet high. The beds dip southward into the hill. In the quarry the rock seems to be quite thin and flaggy and is dark in color. It is most likely the Tonoloway member. This dark limestone, overlain by a more massive blue rock, is hard and has a few fossils on the weathered surfaces. Some limy shales near the base of the quarry seem to grade into the pale green shales of Salina age.

About half a mile north of Washingtonville along the road to Strawberry Ridge, there are several abandoned quarries. These belonged to Messrs. Moser and Seidell and were abandoned on account of flooding. They had been worked steadily until 1910 when an underground stream was struck. Flooded conditions rendered a detailed investigation impossible.

OTHER LIMESTONES

Salina limestones. White in his report on Montour County assigned some beds to the Salina that seem to belong to the Tonoloway. However, within the Salina there are some limestones interbedded with shales that surely belong to the Salina. They seem to have no economic importance.

Tully limestone. The "Tully" limestone has been reported in Liberty Township and can probably be found elsewhere if search is made. It has been described as outcropping in the road at the eastern line of Liberty Township, one mile south of Shillisquaque Creek as "20 feet of shaly limestone, ashen gray on its weathered surface, but dark blue on fresh fracture." It has little, if any, economic value.

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NORTHAMPTON COUNTY

Northampton County is well supplied with limestone of several different grades and suitable for various purposes. It is the principal cement producing county of Pennsylvania and includes within its borders the major portion of what is called the Lehigh Cement District. In importance, the Portland cement industry of the county overshadows all other branches of the limestone industry, yet much limestone has been utilized for other purposes. Many attractive stone houses throughout the county are constructed of local limestone. Among these are the old Moravian buildings in Bethlehem. Old quarries worked for stone for lime burning are common. Some of the stone was burned in kilns near the quarries but some was hauled several miles to be burned. A number of blast furnaces within the county used local iron ores and local limestones. These furnaces are nearly all gone now, but the Bethlehem Steel Co. with its large modern furnaces uses some of the local limestones for flux. With the exception of the cement limestones, practically all of the limestones of the region possess the requisite qualifications for crushed stone for road metal and concrete. An increasing quantity is being crushed each year when normal conditions prevail.

The limestones of Northampton County are in pre-Cambrian, Cambrian, Canadian and Ordovician formations. Nearly all of them are within the Great Valley that crosses the south central part. Saucon Valley, half of which is included within the county and which is an off-shoot of the Great Valley, is similarly floored by Cambro-Ordovician limestones. There are a few detached areas of limestones within the Martinsburg formation to the north of Weaversville.

*Table of limestone formations of Northampton County**

	Thickness in feet
Ordovician:	
Martinsburg shales and slates with some interbedded limestones in a few localities	
Jacksonburg limestone, argillaceous limestones used in manufacture of Portland cement	600±
Canadian:	
Beekmantown limestone, interbedded low and high magnesian limestones	1000±
Conococheague (Allentown) limestone, dolomite limestones containing fossil algae, *Cryptozoon proliferum*	1500±
Cambrian:	
Tomstown limestone, shaly and massive dolomitic limestones	1000±
Hardyston sandstones and quartzites, containing no calcareous matter	250±
Pre-Cambrian:	
Light (Byram) and dark (Pochuck) colored gneisses, principally igneous, no calcareous matter	?
Franklin limestone, coarsely crystalline metamorphic marble containing flakes of graphite and associated with graphitic schist	200±

* This column is arranged according to the classification of the Pennsylvania Survey. The author prefers the U. S. Geological Survey classification which does not recognize the Canadian system, but places the Cambrian-Ordovician contact at the base of the Beekmantown.

CHARACTER OF LIMESTONES

FRANKLIN LIMESTONE

About 2½ miles north of Bethlehem, on the west side of Monocacy Creek, an outcrop of Franklin limestone covers a few acres. The limestone is completely metamorphosed to a coarse-grained white marble containing numerous graphite flakes and many silicate minerals. It is intimately associated with graphitic schist and gabbro although the exact relations of these rocks cannot be determined from the outcrops.

Fig. 29. Limestone areas in Northampton County.

1. Bethlehem Mines Corp. 2. William Roberts. 3. John Walz. 4. C. Warne. 5. T. H. and C. H. Groman. 6. Trumbower Co., Inc. 7. Northampton Quarrying Co. 8. Lawrence Portland Cement Co. 9. Universal Atlas Cement Co. 10. Lehigh Portland Cement Co., Bath plant. 11. Keystone Portland Cement Co. 12. Pennsylvania-Dixie Cement Corp., Plant No. 6. 13. Pennsylvania-Dixie Cement Corp., Plant No. 5. 14. Pennsylvania-Dixie Cement Corp., Plant No. 4. 15. Lone Star Cement Co. of Pennsylvania. 16. Nazareth Cement Co. 17. Hercules Cement Corp. 18. Lehigh Portland Cement Co., Sandts Eddy Plant. 19. Alpha Portland Cement Co.

The rock is similar in character and of approximately the same age as the famous Franklin limestone of New Jersey so extensively quarried in the vicinity of Franklin Furnace and McAfee. The following analyses show the general character of the rock:

Analyses of crystalline limestone quarried by Monocacy Stone Co.

	A	B		A	B
CaO	53.11	52.39	SiO_2	2.08	2.78
MgO	.94	.84	$CaCO_3$	94.74	93.46
Al_2O_3	.21	.69	$MgCO_3$	1.96	1.75
Fe_2O_3	.37	.55	Fe	.26	.39

Sample A, medium grain and dark; B, coarsely crystalline white rock.

A few years ago a quarry was opened along the creek by the Monocacy Stone Co. and considerable stone was shipped to some of the cement mills in the vicinity that require additional high calcium limestone low in magnesia. The rock in this quarry is so crushed and sheared and contains such an unusually large amount of silicate minerals that it was necessary to discard a considerable quantity of the stone and the quarry did not prove profitable. From the surface indications it would seem probable that much better material could be obtained from other parts of the property. An average analysis of 50 tons of stone gave the following results: $CaCO_3$ 90.49, $MgCO_3$ 2.10, SiO_2 7.39.

CAMBRIAN AND CANADIAN LIMESTONES

The three Cambrian and Canadian formations have been described on previous pages in discussing the same formations in Berks and Lehigh counties, and the reader is referred to those pages for further information. Stone from all three of these formations has been quarried for flux, for lime burning, and for crushed stone. The regular position of the Tomstown limestone is near the south side of the limestone valley, with the Allentown and Beekmantown outcropping in successive bands farther north. This order is correct in the main but here and there structural features such as folds and faults have complicated the arrangement.

The Beekmantown, containing low and high magnesian beds, has been used somewhat for cement manufacture by selecting the high calcium stones only. The variations in composition have been well shown at a quarry formerly worked by the Industrial Limestone Co. near Hanoverville on the Lehigh & New England Railroad about 4 miles north of Bethlehem. Some low magnesian layers of the Beekmantown limestone were found originally at this site and, on the assumption that a large body of such stone was present, a cement company called the Lily White Cement Co. was organized and the construction of a Portland cement plant started. High magnesian stone was encountered on further examination and the cement project was abandoned. The quarry did, however, furnish considerable low magnesian stone that was shipped to one of the cement companies but the bulk of the stone was burned for lime. Some gnarly, highly siliceous layers have been crushed for road metal and concrete. Prof.

D. S. Chamberlain, Lehigh University, made a detailed study of some of the layers exposed in the quarry face a few years ago, particularly with reference to a prominent dolomitic bed. A photograph of the quarry (Pl. 34) and a table of analyses are abstracted from his report.

Analyses of limestone from Industrial Limestone Co. quarry, Hanoverville

(D. S. Chamberlain, analyst)

No.	SiO_2	$Fe_2O_3 + Al_2O_3$	$CaCO_3$	$MgCO_3$
1	5.74	3.72	86.75	2.81
2	4.30	1.48	61.80	32.50
3	6.28	10.82	41.06	40.90
4	3.68	1.84	64.80	30.03
5	2.42	12.46	85.50	1.25
6	5.18	17.78	38.10	38.05
7	6.30	1.14	89.25	2.34
8	5.40	1.12	55.60	38.60
9	3.82	17.54	57.65	21.02
10	7.46	0.50	88.94	2.85
11	5.64	1.18	78.00	15.80
12	4.20	0.46	89.85	6.44
13	4.06	9.14	79.55	6.33
14	5.80	5.58	54.53	34.05
15	4.34	10.50	80.00	4.89
16	6.56	0.82	56.85	36.65
17	5.70	0.24	92.45	2.02
18	6.48	4.04	88.45	2.77
19	4.88	0.82	55.44	38.94
21	6.52	0.88	55.15	38.21
22	5.54	5.08	84.97	3.73

The stone shipped from this quarry to one of the cement plants is shown in the following analyses:

Analyses of limestone from quarry of The Industrial Limestone Co.

	A	B	C
$CaCO_3$	94.37	92.70	96.50
$MgCO_3$	2.24	4.15	1.76
$Al_2O_3 + Fe_2O_3$	0.74	0.34	0.28
SiO_2	2.26	1.5	0.54

Along the Central Railroad of New Jersey a quarter of a mile north of Catasauqua the Lawrence Portland Cement Company operated a limestone quarry in the Beekmantown formation for many years. The rocks low in $MgCO_3$ were shipped to the cement plant at Siegfried and those containing too much $MgCO_3$ for cement were sold to the Crane Iron Company for flux. At times the company was able to use 75 per cent of the output for cement but at other times scarcely 25 per cent. In most cases the $MgCO_3$ content for each bed of rock was fairly uniform but in parts of the quarry a certain stratum was suitable for cement but changed in composition sufficiently to render it undesirable in other parts. Under the guidance of the chemist the quarrymen learned to detect the difference in appearance of the rocks low and high in $MgCO_3$ so that their separation was easy. Naturally, steam

shovels could not be used as the different kinds of rocks were thrown down together in blasting. The following analyses taken at approximately equal distances starting from the northwest corner and going in turn along the north, east, and south faces have been furnished by the Lawrence Portland Cement Company:

Analyses of limestones in quarry ¼ mile north of Catasauqua

	1	2	3	4	5	6	7	8	9	10	11
$CaCO_3$	82.12	85.50	79.65	79.08	75.50	85.32	76.94	87.23	92.57	88.30	85.63
$MgCO_3$	4.31	3.44	2.98	3.35	6.07	4.07	4.73	4.53	5.10	3.13	6.04
$Al_2O_3+Fe_2O_3$	3.95	2.14	4.95	5.09	5.41	2.63	4.76	1.87	1.22	3.05	2.85
SiO_2	9.02	7.82	12.91	12.38	12.81	7.43	13.90	5.56	1.94	5.18	5.70

These examples show the care that must be taken when studying the Beekmantown limestones to avoid being deceived as to their real character when there is only a limited outcrop.

JACKSONBURG LIMESTONE

The Jacksonburg limestones outcrop in a definite band that crosses the county, passing through Northampton, Bath, Nazareth, Stockertown, and Martins Creek. The characteristics of the Jacksonburg limestones have been rather fully described in the chapters on Berks and Lehigh counties and will not be repeated here. Throughout Northampton County the division between the basal portion called "cement limestone" and the thicker upper part called "cement rock" is more definite than in the other counties and yet considerable difficulty is experienced at times in making the separation. The "cement rock" portion outcrops just to the south of the Martinsburg slate hills with the "cement limestone" band on the south side next to the Beekmantown limestones.

A plant, whose quarry is located near the northern margin of the belt and working the upper beds, will need to add high grade limestone to the "cement rock," and a plant with a quarry near the southern margin of the belt and working the basal beds may need to add some clay at times. The old Penn Allen and the Dexter (now Penn Dixie) companies show this very well, the former finding it necessary to add limestone from other points, while the latter occasionally is required to add some clay.

In general the "cement rock" toward the western part of the district runs too low in $CaCO_3$ and the plants located there must buy limestone. The rock in the central and eastern part of the belt averages almost the desired composition for Portland cement, but requires at times a small admixture of clay.

The change in composition of the "cement rock" in depth is well shown in the following series of analyses of rock in a 350-foot boring made by the Universal Atlas Cement Company in their quarry at Northampton. The last 40 feet penetrated was evidently the underlying cement limestone while occasional other high lime analyses are explained by the presence of layers of pure limestone interbedded with the argillaceous limestone ("cement rock").

Analyses of "cement rock" in 350-foot boring in quarry of Universal Atlas Cement Co., Northampton

Depth, feet	SiO_2	Al_2O_3 Fe_2O_3	$CaCO_3$	$MgCO_3$	Total
0–5	-------	------	64.61	------	-------
5–10	-------	------	65.54	------	-------
10–15	-------	------	63.85	------	-------
15–20	-------	------	65.29	------	-------
20–25	-------	------	63.00	------	-------
25–30	-------	------	62.07	------	-------
30–35	-------	------	62.09	------	-------
35–40	-------	------	61.17	------	-------
40–45	-------	------	61.23	------	-------
45–50	-------	------	64.01	------	-------
Average of first 59 feet	21.72	7.88	63.27	5.33	98.20
50–55	-------	------	63.57	------	-------
55–60	-------	------	64.91	------	-------
60–65	-------	------	56.55	------	-------
65–70	-------	------	50.52	------	-------
70–75	-------	------	67.92	------	-------
75–80	-------	------	69.26	------	-------
80–85	-------	------	69.10	------	-------
85–90	-------	------	69.19	------	-------
90–95	-------	------	67.09	------	-------
95–100	-------	------	66.25	------	-------
Average of 50–100 feet	21.42	8.26	64.42	4.45	98.55
100–105	-------	------	68.04	------	-------
105–110	-------	------	67.62	------	-------
110–115	-------	------	65.62	------	-------
115–120	-------	------	66.64	------	-------
120–125	-------	------	67.10	------	-------
125–130	-------	------	64.80	------	-------
130–135	-------	------	66.59	------	-------
135–140	-------	------	72.12	------	-------
140–145	-------	------	65.00	------	-------
145–150	-------	------	63.40	------	-------
Average of 100–150 feet	19.36	7.90	66.80	4.33	98.39
150–155	-------	------	66.16	------	-------
155–160	-------	------	64.97	------	-------
160–165	-------	------	66.51	------	-------
165–170	-------	------	64.63	------	-------
170–175	-------	------	65.91	------	-------
175–180	-------	------	69.45	------	-------
180–185	-------	------	69.10	------	-------
185–190	-------	------	68.93	------	-------
190–195	-------	------	65.15	------	-------
195–200	-------	------	69.28	------	-------
Average of 150–200 feet	17.22	8.02	67.44	4.95	97.63
200–205	-------	------	71.35	------	-------
205–210	-------	------	63.44	------	-------
210–215	-------	------	61.72	------	-------
215–220	-------	------	61.21	------	-------
220–225	-------	------	68.77	------	-------
225–230	-------	------	74.70	------	-------
230–235	-------	------	76.85	------	-------
235–240	-------	------	77.54	------	-------
240–245	-------	------	78.40	------	-------
245–250	-------	------	77.71	------	-------
Average of 200–250 feet	16.28	7.00	71.18	4.85	99.31
250–255	-------	------	74.32	------	------
255–260	-------	------	71.39	------	-------
260–265	-------	------	78.10	------	-------
265–270	-------	------	79.99	------	------
270–275	-------	------	76.80	------	-------
275–280	-------	------	71.65	------	-------
280–285	-------	------	74.58	------	-------
285–290	-------	------	75.02	------	-------
290–295	-------	------	73.11	------	-------
295–300	-------	------	72.69	------	-------
Average of 250–300 feet	13.24	7.32	74.78	4.18	99.52
300–305	-------	------	72.24	------	-------
305–310	-------	------	74.70	------	-------
310–315	-------	------	81.41	------	-------
315–320	-------	------	85.82	------	-------
320–325	-------	------	78.92	------	-------
325–330	-------	------	79.26	------	-------
330–335	-------	------	78.40	------	-------
335–340	-------	------	78.40	------	-------
340–345	-------	------	78.15	------	-------
345–350	-------	------	78.06	------	-------
Average of 300–350 feet	11.08	5.88	78.53	3.58	99.07

In addition to the substances given in the above analyses small quantities of TiO_2, FeO, MnO, P_2O_5, SrO, CaS, K_2O, and Na_2O have been found in the "cement rock" of the region. The effect of these in determining the quality of the cement is problematical. H. M. Ullman and J. W. Boyer, in a paper in Chemical Engineer, November, 1909, give a series of determinations of TiO_2 in specimens of "cement rock" from this region. They range from 0.14 to 0.24 per cent.

Meade (5, p. 50) gives a complete analysis made by himself of a sample of "cement rock" from the quarry of the Dexter Portland Cement Company that has practically the correct composition for burning. It is as follows:

Complete analysis of "cement rock" from quarry of Dexter Portland Cement Co.

SiO_2	13.44	CaO	41.84	C	0.75
TiO_2	0.23	MgO	1.94	CO_2	32.94
Al_2O_3	4.55	Na_2O	0.31	H_2O	1.55
Fe_2O_3	0.56	K_2O	0.72		
FeO	0.88	P_2O_5	0.22	Total	100.32
MnO	0.06	S	0.33		

The writer has made careful search for fossils in the "cement rock" of the region but has found only one specimen in the typical black argillaceous limestone. This is a fairly well preserved specimen of a graptolite found in the old quarry of the Coplay Cement Manufacturing Company in Lehigh County. It is probable that the carbonaceous matter of the rock which causes the dark color is mainly due to the remains of graptolites that disintegrated during the metamorphism which the rock has undergone.

The occasional layers of crystalline limestone which are locally interbedded with the true "cement rock" contain abundant fossils, most of which, however, are fragmentary. They can scarcely be recognized except on weathered surfaces. At the large quarry of the Universal Atlas Cement Company and also the one near Howertown many crinoid stems, bryozoa, and brachiopods have been found.

In many quarries it is difficult to determine the bedding planes unless an interbedded pure limestone stratum can be found. Where these are absent the quartz and calcite veins, which, in general, are present along the bedding planes, are useful in determining the structure. Almost invariably the "cement rock" strata are greatly crumpled and yet have low dips. The normal dip is toward the northwest beneath the Martinsburg slates, which constitute the slate hills, but in many quarries some beds can be found dipping in other directions.

When the region was subjected to the great dynamic forces which formed the Appalachian folds the "cement rock" strata were so weak that they yielded by minor folding and faulting, resulting in local thickening of the different layers but without producing high angles of dip. In very few places can one find the "cement rock" dipping more than 45° and usually the dip is much less, while in the adjoining limestone belt vertical or even overturned beds are common.

The crumpled character of the "cement rock," the absence of any beds sufficiently distinct to be recognized in different openings, and the lack of any continuous or approximately continuous section across the belt normal to the strike render the exact determination of the thickness impossible. The local thickening of the beds due to compression also needs to be taken into account in any estimates of thickness.

In the 350-foot bore hole of the Atlas Cement Company described above, 310 feet seems to be "cement rock" and the last 40 feet to be the underlying "cement limestone." The rocks here, although somewhat crumpled, were so nearly flat that we can safely assume 300 feet of cement rock strata. As the bore hole was started in the bottom of the quarry with somewhat more than 100 feet of "cement rock" above it, the total thickness of "cement rock" in that place is at least 400 feet. This is not believed to be the maximum thickness within the region.

This decided difference in thickness of the "cement rock" may be partially due to local thickening as the rock yielded under compression at the close of the Ordovician and Carboniferous periods, but is mainly explained by a greater deposition of muddy calcareous beds in the region of Lehigh River than took place elsewhere.

The "cement rock" rests conformably upon the underlying "cement limestone." In some places the basal beds seem to dovetail into the

upper beds of the underlying purer limestone. This is seen in the quarries of the Pennsylvania Cement Company (now Penn Dixie) east of Bath.

The "cement rock" is conformably overlain by the shales and slates of the Martinsburg formation. In many places in the district glacial clays containing many cobbles and boulders overlie the "cement rock." This overlying debris, which must be removed before the rock is blasted down, is as much as 15 feet thick in depressions in the former land surface, although the average thickness of this cover is probably less than 5 feet.

MARTINSBURG LIMESTONE

In the vicinity of Catasauqua and Seemsville some limestones rather high in magnesia appear to be interbedded with the Martinsburg slates. These have been quarried in several places to get stone to burn for agricultural lime and a small amount of stone has been quarried for road metal. These quarries have all been idle for several years.

Inasmuch as the author intends shortly to prepare a detailed description of the geology and mineral resources of Northampton County for publication by this Survey, descriptions of all the quarries will not be given here. Instead little more will be attempted than to describe the working quarries and the special adaptabilities of the limestones of the county.

GENERAL UTILIZATION

Building Stone. Notwithstanding the fact that there are some fine old stone houses built of local limestones there is not a quarry of any consequence within the entire county that is being worked or has recently been worked for the purpose of obtaining building stone. Occasionally walls and foundations are constructed with limestones from the Tomstown, Conococheague (Allentown), or Beekmantown but it is rare in recent years to have an entire house built of this material. The principal reason for this is the lack of good stone. Perhaps the chief reasons for this lack of good stone are the shattered character of the rock, the irregularity of the joint planes, the curvature of the beds and the presence of numerous veins of calcite and quartz, all of which are the result of the intense compression to which these rocks have been subjected at several different times since their deposition. Other reasons are the irregularity of the beds and their great variation due to the shallow water conditions that prevailed throughout the greater portion of the periods of deposition. Under these conditions rectangular blocks of rock are difficult to obtain, the amount of waste rock is excessive, and the labor required to dress the stones is prohibitive. In certain quarries some of the strata might be used to advantage for building and the less desirable stones used for ballast or for flux.

Another objection to some of the limestones for buildings is their change of color on weathering. Most of the limestones are dolomitic but the magnesia content varies in the different layers. When fresh the rock is all bluish but on weathering the more dolomitic layers become much whiter than the others. The limestones that border the cement rocks have a tendency to become blotched on weathering on account of their heterogeneous composition.

Notwithstanding these difficulties, however, limestone has been used in the past for foundations and occasional buildings and will no doubt long continue to be quarried for local use.

Fluxing stone. The Tomstown, Conococheague, and Beekmantown limestones have been worked to supply fluxing material for the numerous iron furnaces that have been operated between Easton and Catasauqua. Most of the furnaces were built when the iron mines of the region were in operation and have since been abandoned but, in a few places, especially in the Bethlehem district, the small furnaces have been replaced by large ones requiring far more flux and they in part still rely upon local quarries for their supply.

Although the limestones of the area are being used extensively it cannot be claimed that they are entirely satisfactory. The great advantage in their favor is their proximity to the furnaces. Considerable limestone of superior quality is shipped into the region from New Jersey and from Lebanon County. On the other hand the Parryville Iron Company at Parryville long obtained fluxing limestones from a quarry near Northampton and the New Jersey Zinc Company operated a quarry at Allentown to obtain flux for its Palmerton plant.

The worst feature of the limestones of the area for flux is the presence of occasional sandy or shaly beds with a high percentage of silica. Solution cavities filled with clay are frequently encountered. These are more abundant than they would have been if the strata had not been so greatly shattered and deformed by earth movements. Deep solution pits or pockets filled with clay are numerous and make the removal of the overburden expensive. These rocks are so variable in character that careful sampling and usually core drilling are required to determine their availability for use for flux. Experience has shown that most properties so prospected have been rejected as undesirable.

The largest quarry now being operated in the region for limestone flux is owned by the Bethlehem Mines Corporation and is located immediately across Lehigh River from the Bethlehem Steel Co. plant. The rock belongs to the Conococheague formation. The quarry is about 1500 feet long and has been advanced into the hillside about 600 feet. The height of the quarry face is about 70 feet. The rock is a dolomite which is hard but considerably shattered. Although the strata are both folded and faulted the general strike is northeast-southwest with an average dip to the northwest of about 20°. The average composition is about as follows: $CaCO_3$, 53 per cent; $MgCO_3$, 41; $Al_2O_3+Fe_2O_3$, 2; SiO_2, 4.

The quarry was acquired by the present owners in 1916. Previously it had been operated for commercial stone and for lime burning by the Chapman Quarries Co.

The larger sizes, 2½ to 6 inches, are used for blast furnace flux and the smaller sizes, graded into 9 classes between dust and 2½ inches, are washed and sold for commercial purposes.

The location of the quarry in proximity to the blast furnaces is the most desirable feature of this operation. The stone is transported across Lehigh River and the railroads to the furnaces by aerial tram. The greatest obstacle in the operation of the quarry has been the heavy clay overburden and the occasional deep clay pockets and rotten stone. The quarry and crushing plant are well equipped with electric shovels,

steam haulage to the crushing plant, crushers, screens and washing plant. The estimated annual production is 360,000 tons of fluxing stone and 250,000 tons of washed commercial stone. Since 1916, the quarry has furnished 2,930,000 tons of fluxing stone and 1,340,000 tons of commercial crushed stone.

The Bethlehem Steel Company at one time obtained similar fluxing stone from quarries at East Allentown and some Tomstown dolomite stone, in which there was considerable shaly material, from near Redington. These quarries are now abandoned.

One of the extensive quarries once worked for flux, but abandoned perhaps 40 years ago, is the Glendon quarry along Lehigh River and Central Railroad of New Jersey, about 2 miles southwest of Easton. It was formerly owned by the Glendon Iron Works and worked to supply their furnaces with fluxing stone. The quarry is approximately 1200 feet long, has been advanced into the hillside about 400 feet, and has a face about 175 feet high. The flat quarry floor is just about the level of the railroad tracks. The stone is a dolomite belonging to the Conococheague (Allentown) formation. The beds are moderately thick, averaging about 1 foot, but with some beds 2 feet in thickness. There are a few interbedded black shale bands. Some layers contain *Cryptozoon proliferum*. Near the front of the quarry the beds are complexly folded and faulted; farther back they are fairly regular but show one broad anticline. The general strike is about N.52°E. with a dip of 20°SE. The overburden was thin, probably averaging no more than 3 or 4 feet.

Lime. Most of the quarries of this region have been worked for limestone to be burned for lime. As in all other parts of the State, the small lime kilns operated for local supply have now been largely abandoned, athough here and there some of these small kilns still are operated at times. In only a few places has any large lime plant been developed for the shipment of lime to other sections. Unless extreme care is taken it is not possible to produce lime of uniform composition. The lime produced in almost any part of the county is satisfactory for agricultural use and for plastering but it would be difficult to produce lime for the chemical trade. One of the most important lime plants of the region was that of the Industrial Limestone Company near Hanoverville, described on a previous page. This company had well equipped kilns and operated for several years, but has recently been abandoned.

It is doubtful whether there will be any large lime operations in Northampton County inasmuch as the region can be so readily supplied with the highest quality lime from Montgomery, Chester, and Centre counties, and the use of lime on the soils has greatly declined.

Crushed stone. As in other parts of the State, the Cambro-Ordovician limestones of this section have been extensively used for roads and for concrete aggregate. Except for occasional shaly bands, practically all the stone will meet the rigid specifications of the State Highway Department. Scores of quarries have been opened to supply local demands but most of them are of moderate size. In the vicinity of the larger towns, some fairly large quarries have been developed to supply the demands for concrete material.

In the vicinity of Easton, a number of quarries have been worked for crushed stone for general concrete and highway use. Along the Delaware River road below Easton, the Tomstown and Conococheague limestones have been worked in several places. Most of these were opened to get stone for burning and have long since been abandoned. One of these just below Raubsville is of large size. The only active quarries in this section now are two that are producing crushed stone only. William Roberts is operating a quarry about one-fourth mile south of the Lehigh Valley Railroad bridge. The stone is a bluish-gray dolomite with a few shale partings. Some oolitic beds and black flint concretions are noticeable. The quarry face is about 100 feet high. The strata are folded but in general dip gently to the north and east. The beds are fairly thick. The quarry is equipped with a steam shovel and two crushers. The capacity is said to be 500 tons per day. The stone is used for highways and concrete structures.

The John Walz quarry is located along Delaware River about a mile below the Lehigh Valley Railroad bridge. The stone is a hard dolomite suitable for crushed stone. The quarry face is about 70 feet high.

In recent years, C. Warne has worked a quarry about half a mile northeast of the old Glendon quarry which is known as the 25th Street quarry. The stone is a fine-grained, dolomitic, siliceous limestone of the Conococheague formation containing *Cryptozoon proliferum.* Some of the beds are from 3 to 6 feet thick. The strike is N.65°W. and the dip 15°NE. The quarry is about 150 feet long, 100 feet wide, and has a face 100 feet in height. The stone is crushed and sized for road metal and concrete work.

North of Easton, there are a number of old lime quarries almost any of which might be worked for crushed stone if the market conditions should warrant.

In the region of Freemansburg several quarries for crushed stone have been worked in the Conococheague dolomitic limestones.

About Bethlehem there is demand for considerable crushed stone and several quarries have been worked for this purpose. The large quantity now being produced as a by-product by the Bethlehem Mines Corporation at their fluxing stone quarry between Bethlehem and Freemansburg prevents the opening of many other quarries. The quarry along Monocacy Creek just north of Bethlehem known as Lerch's quarry, now worked by T. H. and C. H. Groman has long been worked for crushed stone. The stone belongs to the Conococheague formation and is a hard dolomite with some sericite developed along the bedding planes. *Cryptozoon proliferum* is abundant through the quarry and ripple marks, oolite and edgewise conglomerate are common. A fine anticlinal fold is exposed as well as a prominent fault.

The Beekmantown limestone has been crushed for road metal and for concrete along the Tatamy-Nazareth road, just west of Tatamy and about a mile east of Nazareth. The stone is partly high and partly low magnesian interbedded. Both varieties are suitable for crushed stone. The Trumbower Co., Inc., has been the principal operator in this region.

In the vicinity of Northampton and Catasauqua a number of quarries in the Beekmantown were once worked for fluxing stone for blast furnaces at Hokendauqua, Catasauqua, and Perryville, later used for

cement where the high calcium beds could be separated, and now mainly are closed. The only one still in operation is the quarry of the Northampton Quarrying Co. located about one mile southeast of Northampton. The quarry contains both low magnesian stone, that is at times separated and sold to the nearby cement companies, and hard, dark blue, dolomitic limestones that are only suitable for crushed stone but particularly adaptable for that use. In general the beds dip steeply to the south but a number of folds and faults produce a complicated structure. The structure, however, is simple as compared with a quarry located about half a mile to the west where the beds have been so intricately folded that it is extremely difficult to determine what has taken place. The quarry face is about 90 feet high. The clay overburden over part of the quarry is heavy. Some analyses of the stone sent to blast furnaces are given in the table of analyses at the close of this chapter. Some of the stone sent to cement plants contains over 89 per cent $CaCO_3$ and 3.44 per cent $MgCO_3$.

CEMENT MANUFACTURE

The manufacture of Portland cement is one of the chief industries in Northampton County and a string of cement plants extends entirely across the county in the belt where the Jacksonburg limestones outcrop.

Along Lehigh River the outcropping band of Jacksonburg "cement limestone" and "cement rock" is about 2 miles wide and here close to the river are located the plants of the Lawrence Portland Cement Co. in the north part and the Universal Atlas Cement Co. in the east part of the borough of Northampton.

The Lawrence Portland Cement Co. has been manufacturing Portland cement since 1889. For some time the cement rock was quarried close to the plant in a narrow deep quarry along the Lehigh Canal. This was abandond several years ago and the stone has since been obtained entirely from the old Bonneville quarry about half a mile east of the plant. The quarry is a deep one but it has been profitable to work because of better stone being obtained at depth. The dry process of cement manufacture is used. The plant has 13 kilns of various sizes and produces 2,700,000 barrels of cement annually.

The Universal Atlas Cement plant in east Northampton has 3 mills, each of about 10,000 barrels daily capacity. In one of the mills high aluminum cement has been produced by the use of bauxite. Also a white cement is produced by the use of white clay and high grade limestone. The quarry covers several acres and is about 4,000 feet long and averages from 80 to 100 feet in height. Formerly another quarry near the office was worked and for a time stone was quarried near Howerton.

The Bath plant of the Lehigh Portland Cement Co. is located about 1½ miles southwest of Bath. Two quarries are supplying the mill. The larger one located to the north of the plant is opened in the "cement rock" and the lower on the south side of the plant is in the "cement limestone." The deficiency in $CaCO_3$ of the "cement rock" is largely met with an excess of the same material in the "cement limestone." The plant has a daily capacity of about 3,000 barrels.

The Keystone Portland Cement Co. located about half a mile southwest of Bath is the newest cement plant in the district. The quarry

furnishes a good grade of stone. The mill has four kilns and uses the wet process of manufacture. The capacity is 2,500,000 barrels a year. The Pennsylvania-Dixie Cement Corporation plant No. 6 (formerly the Pennsylvania Cement Co.) is located about half a mile east of Bath. The south part of the quarry is in the "cement limestone" and the north part in the "cement rock." Clay pockets have been troublesome and stone has to be brought from the quarry of plant No. 4 three miles to the east. The plant has 11 kilns and a daily capacity of 5,000 barrels.

The Pennsylvania-Dixie Cement Corporation plant No. 5 (formerly the Penn-Allen Cement Co.) is located 1¼ miles northeast of Bath. The stone quarried at the plant was so deficient in lime that a large amount of high grade limestone had to be purchased and an aerial tram was constructed to bring stone from the quarry of plant No. 4 two miles to the east. The plant has not been in operation for some time. It is provided with 8 kilns and has a daily capacity of 3,000 barrels.

The Pennsylvania-Dixie Cement Corporation plant No. 4 (formerly the Dexter Portland Cement Co.) is located one mile west of Nazareth. The quarry is mainly within the "cement limestone" belt and yields excellent stone sufficiently high in $CaCO_3$ for the mix. It varies somewhat in different parts of the quarry. The plant has 8 kilns and a daily capacity of about 4,000 barrels.

The Lone Star Cement Co. of Pennsylvania (formerly the Phoenix Portland Cement Co.) is located about one-fourth mile west of Nazareth. The quarry is mainly in the "cement limestone" and furnishes a fine grade of stone. The plant has 5 kilns and an annual capacity of 2,000,000 barrels.

The Nazareth Cement Co. is located in the southeastern part of Nazareth. The quarry is in a synclinal fold of the Jacksonburg limestone. The stone quarried is of excellent grade and so high in $CaCO_3$ that occasionally some clay is added. The plant has 8 kilns and produces 2,200,000 barrels a year.

The Hercules Cement Corporation is located about half a mile west of Stockertown. The quarrying area is somewhat limited in width and hence the quarry is being deepened. There are 9 kilns with an annual production of 2,250,000 barrels.

The Sandt's Eddy plant of the Lehigh Portland Cement Co. is located about 1½ miles west of Martins Creek Station. This is one of the newest plants of the district and one of the two plants of the county employing the wet process of manufacture. The quarry yields a good quality of stone.

The Alpha Portland Cement Co. has one of its plants in Northampton County at Martins Creek Station with two mills (No. 3 and 4). The quarry is mainly within the "cement limestone."

Clay. As mentioned above, some of the cement plants near Nazareth are compelled to use a small quantity of clay with the cement rock to make the proper mixture for Portland cement. In most cases this is the local clay overlying the cement rock and represents the residuum of insoluble materials left when the soluble portions of the rock were removed in solution. Some of it has been transported and deposited by the waters resulting from the melting of the ice sheets

which once invaded the region. The glacial clays contain occasional cobbles and boulders.

At one time the Nazareth Cement Company operated a small clay pit near the mill but in most places the thin deposit of clay overlying the cement rock is more than sufficient for the needs of the plants. The above-mentioned company furnishes the following partial analyses of the local clays used.

Analyses of local clays used in manufacture of cement

CaO	.78	.30
MgO	2.70	1.25
$Al_2O_3 + Fe_2O_3$	20.62	20.09
SiO_2	63.10	70.10

Limestone from other regions. Several companies operating in the region who are compelled to buy limestone to mix with their cement rock, bring it from some distance beyond the borders of the district. The Annville limestones of Lebanon County, Pa., are used in several plants, and also some Franklin limestone from New Jersey.

Analyses of Trenton (Annville) and Franklin limestones

	A	B	C	D
$CaCO_3$	97.11	96.67	96.60	94.29
$MgCO_3$	1.12	1.34	2.54	3.14
Al_2O_3	0.45	1.77 (Al_2O_3 + Fe_2O_3)	0.36	2.13 (Al_2O_3 + Fe_2O_3)
Fe_2O_3	0.45		0.36	
SiO_2	0.36	......	0.46	......

A. Annville limestone analyzed by R. K. Meade.
B. Average of 9 samples of Annville limestone analyzed by Atlas Cement Co.
C. Franklin limestone analyzed by R. K. Meade.
D. Average of 19 samples of Franklin limestone analyzed by Atlas Cement Co.

Quarry methods. The quarry methods used by the cement companies are similar throughout the district. If possible the quarry is opened in the side of a hill and the tracks are run in on the level. As the quarry is extended the quarry face becomes higher. In some places, however, it is necessary to open a quarry by excavating in a fairly level surface and then the rock must be hauled up an incline to the plant.

In almost every quarry the composition of the rock varies so much in different parts that it is advisable to have an extensive face with tracks radiating to different points in order to obtain a mixture of uniform composition by combining the rock of high and low lime content.

Formerly the rock was quarried in benches by using small drills and small blasts. Now, however, the companies have found it more economical to blow down enormous masses of rock at one time, in some places more than 30,000 tons. To do this churn drill holes are put down about 10 to 15 feet back from the quarry face and about the same distance apart and driven to the level of the bottom of the quarry which is usually nearly 100 feet. These holes are then charged with dynamite and all are fired simultaneously by electric exploders. The rock is so easily shattered that these great blasts break most of

it sufficiently to be loaded into cars. The larger blocks are broken by small charges of dynamite placed in holes made by compressed air hand drills.

The companies use steam or electric shovels for loading the rock into cars. In the quarries that are driven into a hillside on the level small locomotives or horses are used to haul the cars to the mill. Where the quarry is sunk below the level of the mill the cars are pushed by hand or hauled by mules to the foot of the incline where they are attached to a cable to be hauled up the slope. The rock is dumped into a bin or directly into the gyratory or primary jaw crushers.

Manufacture. In general there is little variation in the methods employed throughout the region for the manufacture of Portland cement although somewhat different types of machinery are used. The different stages are (1) coarse grinding, (2) drying, (3) fine grinding, (4) calcining, (5) cooling or seasoning, (6) mixing with gypsum and grinding the clinker, (7) seasoning in storage house preparatory to bagging. Where the wet process is employed the stone is ground wet and then conducted to slurry tanks and from there to the kilns. As these various processes have been described in so many publications dealing with the technical side of cement manufacture, they will be described only briefly here.

(1) The first stage of coarse grinding is done almost exclusively by great gyratory or jaw crushers. The rock properly combined is fed to the crushers from bins, dumped directly from the cars, or brought from rock house by belt conveyor. In some mills, the crushed rock passes to a set of smaller gyratory crushers or rolls.

(2) The rock fragments are dried in short rotary kilns which in a few plants are connected with the ends of the burning kilns and thus use the heated gases that would otherwise escape at once into the air.

(3) Various kinds of machines are used for the fine grinding—ball mills, tube mills, Huntingdon mills, Griffin mills, cominuters, Fuller-Lehigh pulverizers, etc. Most of the mills grind the rock so that 95 per cent will pass through a 100-mesh screen and approximately 85 per cent will pass through a 200-mesh screen.

(4) From the mills the pulverized rock is taken to bins and from them is fed into the kilns. At present all the companies use rotary kilns. The older and smaller kilns are gradually being replaced by larger sizes. At first nearly all were about 40 feet long, then 60, 80, and 100 feet; the more recent ones installed are over 200 feet long and 8 to 10 feet in diameter. It has been found that the fuel costs are considerably less in the larger kilns and the capacity is greatly increased.

The kilns are fired with coal ground so fine that about 95 per cent will pass through a 100-mesh screen. The coal dust is forced into the kiln by fans or compressed air.

The first kilns used in the district were upright. Several of these, called Schoefer kilns, are still to be seen at the plant of the Coplay Cement Manufacturing Company in Lehigh County. They consist of three compartments, an upper heating chamber, a middle clinkering

chamber, and a lower cooling chamber. The pulverized rock was mixed with water and moulded into bricks which were first dried and then carefully placed in the upper chamber by hand. The material passed in turn through the other chamber and was drawn out at the base. These kilns were not satisfactory as the material was not uniformly burned, the amount of labor required was excessive, and the production limited, as scarcely more than 100 barrels of cement could be burned in each kiln daily. On the other hand the fuel consumption was much less than that required in the rotary kilns, ranging from 45 to 65 pounds of coal per barrel of cement.

(5) In some mills the clinker is stored under cover for a short time before being ground but the practice of storing it in the open where it is allowed to season for several weeks before grinding has been generally adopted.

(6) After cooling and seasoning the clinker is taken to mills for regrinding. In almost every mill the same type of machinery is used for grinding the clinker that is employed in pulverizing the rock. Before grinding, a definite proportion of gypsum is added to the clinker to retard the setting of the cement.

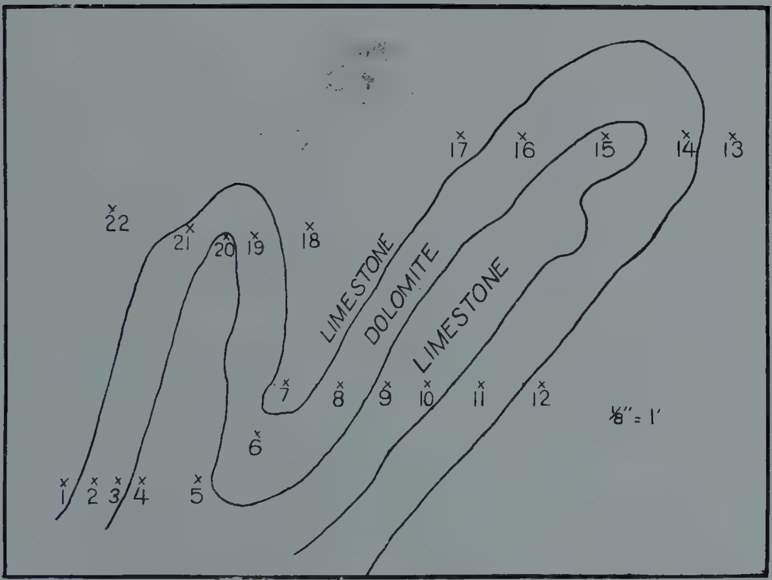
(7) From the mills the cement is taken to the storage bins where it remains for some time to season and is then withdrawn for shipment. It is sometimes shipped in barrels holding 380 pounds, but almost entirely in paper or cloth bags holding 95 pounds. The Bates valve bag is used in the district.

Economic considerations. The cement industry of the Lehigh district has undergone remarkable changes since it started. The price fell steadily before the war from $3.00 to $0.65 per barrel, but since then has been normally considerably higher. The output, with few exceptions, has been increased from year to year, and yet the market for the cement from this district has been gradually restricted on account of the building of plants in sections of the country formerly supplied by the Lehigh product. In few other parts of the country can cement be produced at so low a price as in this district and the condition of the industry during normal times continues promising regardless of the competition and reduced prices. Increased efficiency has resulted and the Lehigh district plants are models for other cement companies throughout the country. Experimentation still continues and new types of machinery, new details in manufacturing, and improved quality of cement have resulted.

In some cases the companies have failed to appreciate the importance of a careful study of the structure of the cement rock strata by which their quarries could have been operated more economically. Likewise several of the plants might have been located more advantageously had the geology of the region been carefully studied in advance.

The possession of cement rock of so nearly the correct composition for Portland cement, a very unusual occurrence, and the close proximity to the great industrial centers of the country are the two great assets that have enabled the Lehigh cement district to achieve and maintain its pre-eminent position. With the skill and efficiency acquired by years of experience and the increasing demand for cement, the cement companies may look forward to many years of prosperity.

A. Folding in Industrial Limestone Co. quarry, Hanoverville, Northampton County.



B. Diagram showing location of samples taken in quarry of Industrial Limestone Company, Hanoverville, Northampton County.

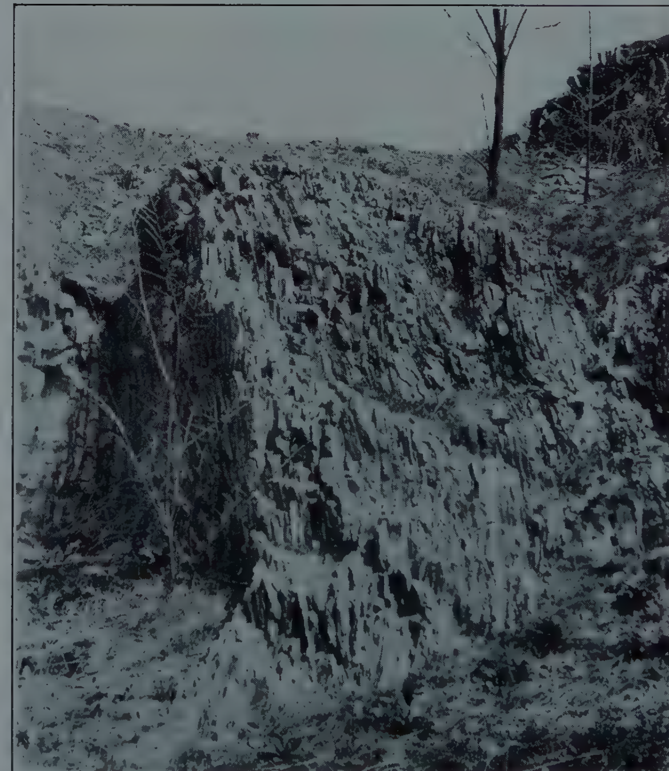
Pennsylvania-Dixie Cement Corp., Plant No. 4, at Nazareth, Northampton County; annual capacity, 1,600,000 bbl.

Helderberg limestone quarry, Blain, Perry County.

A. Shows upper thin-bedded strata greatly folded with lower only gently disturbed.

B. Closer view of upper portion.

A. Quarry in Onondaga limestone along the Juniata River at Half Falls Mountain, Perry County.



B. Thin bedded Martinsburg limestone, east of Harpers Tavern, Lebanon County.

A. Booth and Flinn quarry in Loyalhanna limestone at Long Bridge, one mile northwest of McCance P. O., Westmoreland County.

B. Quarry in Greenbrier limestone along National Pike, east side of Chestnut Ridge, Fayette County.

A. Common use of Pennsylvania marble in rows of houses in Philadelphia 50 years ago.

B. Founders Building, Girard College, Philadelphia, built of Pennsylvania marble in 1832.

A. Cement rock quarry, face 90 feet high, in Lehigh district.

B. Modern lime kiln near York, York County.

A. Marble from West York.

B. Marble drill cores from York.

Additional analyses of Cambro-Ordovician limestones of Northampton County

	1	2	3	4	5	6	7	8a 19–25′	8b 25–30′
CaO				31.95					
MgO				18.05					
Al_2O_3	0.58	2.20	1.10	2.62	.73	1.95	1.89		
Fe_2O_3						1.05			
SiO_2	1.90	4.77	1.68	2.70	4.95	6.94	5.67	0.89	2.02
S	0.020						0.21		
P	0.006						0.006		
$CaCO_3$	52.16	53.43	53.77		52.37	47.66	50.49	54.7	53.5
$MgCO_3$	43.28	41.43	42.92		41.74	42.26	41.04	43.5	43.0

	8c 30–40′	8d 40–50′	8e 50–58′	8f 66–70′	8g 70–80′	8h 80–85′	8i 85–90′	8j 90–100′
$CaCO_3$	47.5	55.0	52.8	55.0	53.2	49.3		
$MgCO_3$	34.0	41.5	41.2	43.5	41.5	35.2		
SiO_2	11.92	1.79	3.63	0.82	2.81	3.69	5.04	9.76

	8k 100–110′	8l 110–120′	8m 120–130′	8n 130–140′	8o 140–149′	9	10a	10b	11
$CaCO_3$						82.44	81.41	87.66	88.12
$MgCO_3$						10.26	11.49	4.97	4.71
Al_2O_3						2.30	1.89		1.33
Fe_2O_3							0.39	1.05	0.26
SiO_2	5.65	3.77	1.59	3.54	4.59	4.74	4.50	5.30	4.70
P								0.010	
S						0.026			

1. Tomstown limestone quarry at Island Park, south side of Lehigh River, Northampton County. Average of 108 cars shipped to Thomas Iron Co. Analysis by Thomas Iron Co.

2. Tomstown limestone. Redington quarry of Bethlehem Steel Co., Northampton County. Average analysis of stone quarried during 1916. Analyzed by Bethlehem Steel Co.

3. Conococheague limestone. Easton Lime Company's quarry along Bushkill Creek, Easton, Northampton County. Analyzed by P. Shimer.

4. Tomstown limestone. O. E. Leh quarry at Redington, Northampton County. Analysis by Bethlehem Steel Co.

5. Conococheague limestone. J. M. Laubach quarry, Freemansburg, Northampton County. Average analysis of 110 cars made by Bethlehem Steel Co.

6. Conococheague limestone. Wagner's quarry, west side of Saucon Creek, ½ mile southwest of Hellertown, Northampton County. Analysis made by Bethlehem Steel Co., is average of six month's run.

7. Conococheague limestone. Henry Schweitzer's quarry midway between Freemansburg and Altona, Northampton Co. Analysis by Bethlehem Steel Co.

8. a to o. Conococheague limestone. Drill test hole at Chapman quarry of Bethlehem Steel Company along C. N. J. R. R. between Bethlehem and Freemansburg. Analysis by Bethlehem Steel Co.

9. Beekmantown limestone. Fogel's farm near Hecktown on L. & N. R. R., Northampton County. Analysis made by Bethlehem Steel Co., is average of 10 samples collected by C. A. Buck.

10. Beekmantown limestone. Northampton Quarrying Co.'s quarry, 1 mile east of Northampton, Northampton County. a. Analysis by Bethlehem Steel Co. b. analysis by Thomas Iron Co.

11. Beekmantown limestone. Calcite Company quarry, ¾ mile southeast of Northampton, Northampton County. Analysis by Bethlehem Steel Co.

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NORTHUMBERLAND COUNTY

Northumberland County is well provided with limestones as the Helderberg limestone in narrow bands loops back and forth through the county. This repetition of the same series of limestones is due to several anticlinal and synclinal folds.

In addition to the Helderberg, some other limestones in places may be pure enough to be of slight economic importance. These are the Tully limestone that lies immediately above the Hamilton, another that seems to lie within the Hamilton and has been called the Upper Selinsgrove limestone, a lower limestone that is believed to be the Onondaga although it has been called the Lower Selinsgrove limestone, and some impure limestones that may be of Upper Salina age although perhaps in part Tonoloway.

HELDERBERG LIMESTONES

The Helderberg limestone first appears in the northern part of this county about three miles south of the northern border, just north of the town of Dewart, on the Susquehanna. Its course is a general southeast trend, passing south of Turbotville, to the Montour County line. Then it swings back and follows a southwest trend, outcropping all along Limestone Ridge, particularly in the neighborhood of Limestoneville, and continues westward to the south side of Milton. It turns back in Union County and follows the north side of Montour Mountain from Montandon eastward. Another belt is continuous across the county from near South Danville to the river just north of Northumberland. Another strip of outcrops of the Helderberg is found 2 to 3 miles south of Sunbury, and still another between Dalmatia and Urban.

The chief quarries in the county are in the Turbotville, Milton, and Dalmatia areas. These quarries have been in operation during recent years and most of their product is burned lime, although a great deal of the material has been used as ballast on State highways under construction in the vicinity of the quarries.

At one time or another the Helderberg limestones have been quarried and burned for lime in many places in Lewis, Delaware, Turbot, Chillisquaque, Point, Upper Augusta, Lower Augusta, Lower Mahanoy, and Jordan townships. Most of these quarries have long since been abandoned and little information is available concerning them. Some of them worked the horizons that yielded a high quality lime, but others worked shaly impure beds that produced lime possessing value for agricultural use but not sufficiently pure for other purposes. The general characteristics of the Helderberg limestones are shown in some of the sections given below.

DESCRIPTION BY DISTRICTS

Turbotville Area. The chief quarrying area of Northumberland County lies within 1½ miles of Turbotville, a small town in Lewis Township, on the Berwick branch of the Pennsylvania Railroad. The quarries are located west, southwest, and south of the town.

The limestone ranges from a dark, rather slaty limestone belonging to the Tonoloway formation to the more massive and fossiliferous, and, in places, nodular limestone of the Keyser formation.

The principal working quarries in 1929 were those of Orvis Greenly (part of which was formerly the A. P. Yerg quarry) and Cyrus Gessner located one mile southwest of Turbotville.

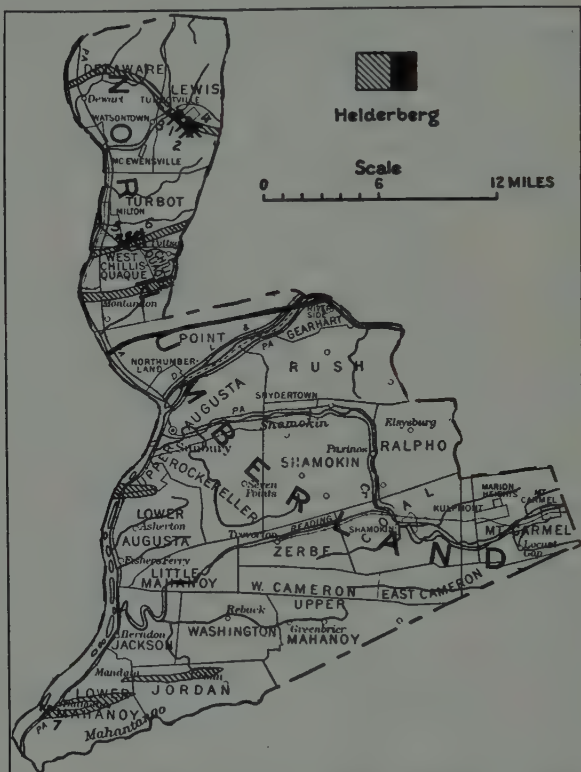

Fig. 30. Limestone areas in Northumberland County.

1. Orvis Greenly. 2. Cyrus Gessner. 3. John Moser. 4. Abner Showers. 5. Borough of Milton quarry. 6. Peter Clemmens. 7. Susquehanna Stone Co.

Section exposed in Orvis Greenly quarry

	Feet
Keyser limestone:	
Shaly limestone, beds from one to three inches thick	7
Bluish gray limestone beds ranging from 1 inch to 4 feet thick	10
"Cement" beds, dark blue to black	6
Gray to grayish blue limestone	20
Dark blue to black limestone used for road ballast	15
Tonoloway limestone:	
Shaly and platy limestones	?

The Greenly quarry face is about 600 feet long. The beds strike N24°W. and dip 5°NE. There is very little overburden. The entire face of stone is shot down and crushed for road purposes. A small

amount has been pulverized for fertilizing purposes. The quarry is idle during the winter.

The Cyrus Gessner quarry, which is approximately 60 feet high and fully 800 feet long, is directly over the hill south of the Greenly operation. The overburden is deep. The limestone is practically the same as in the Greenly quarry. The chief bed is a very dark to almost black limestone which has a characteristic glassy fracture and is about 15 feet thick. It is made up of beds that average a foot in thickness. A bed called "niggerheads" overlies the black limestone and is about eight feet thick. It corresponds with the so-called "cement" beds of the Greenly quarry. Above the "niggerheads" is one foot of shaly limestone. This latter bed contains many shale laminae. The shaly beds alternate with a bluish to gray massive limestone. The rock weathers to a buff yellow. No fossils were found.

Throughout most of the quarry, the beds are practically flat but a roll causes a decided dip in one place. In 1929 most of the stone quarried was burned for lump or ground lime. Part was sold as crushed stone for road construction. For the latter use, care must be taken to avoid the rotten or shaly layers.

About one mile west of Turbotville, John Moser was operating a small quarry in 1929 and selling crushed stone.

Abner Showers was also working a quarry about 1½ miles south of Turbotville and crushing stone for his own use. The quarry face is about 22 feet in height. The stone is massive, blue in color, and appears to be of good quality. Stone was formerly burned here.

The quarries of the Turbotville area for the most part show an upper limestone which is quite shaly and in some places quite sandy. The beds average about one to two inches thick and make up a total of six feet. It overlies a massive, blue-gray limestone which is directly above a harder and more massive layer of blue limestone. This latter has been erroneously termed a "cement" bed by the district quarrymen. It does not produce good lime.

Under the so-called "cement" bed is the blue gray limestone which represents the Stormville of White. This is probably the middle Keyser of Reeside. It is directly above the blue and flaggy limestone of the Gessner quarry, and is present also in the abandoned Williamson quarry, where samples for chemical analysis were obtained. The analyses showed 92 per cent calcium carbonate with less than 3 per cent magnesium carbonate.

Milton Area. The limestone quarried in the vicinity of Milton is the Tonoloway, and is found on the north slope of the Milton sub-axis. It is not quite as pure in this particular locality as in some other sections, so that most of the quarries opened in this area have been abandoned. The ones that have operated recently crushed the material. The only quarries worked recently are the Borough of Milton quarry and one belonging to Peter Clemmens. Both were idle in 1929.

The upper portion of the Milton Borough quarry shows a very crumbly limestone and contains some thin beds of massive pure limestone. On tracing this bed across to a neighboring quarry it was found that the *Stromatopora* bed appeared, hence this quarry is in the Keyser. To the north end of the quarry the platy and shaly beds of the Tonoloway appear. There are numerous clay veins and pockets, as well as much cave travertine, and also many calcite veins.

The main part of this quarry was driven into a shaly limestone; the lower part of which is hard and black. Above this black bottom layer is a gray rock which breaks into fine pieces, somewhat angular, with a glassy fracture. This bed is eight feet thick. It in turn is overlain by a more or less chocolate-colored bed of about the same thickness but more massive. One bed is composed almost entirely of branching bryozoa.

Between the three massive beds the rock is quite shaly, and the beds are from one to two inches thick. In the upper part of the quarry the rocks are deeply weathered, which probably is responsible for the shaly appearance of the beds. Clay pockets up to one foot thick appear in the rocks. Calcite veins are quite numerous. From all appearances the quarry is along the southern outcrop of the Helderberg.

Pick and shovel methods were used in the quarry and the caving of overlying rock by means of undermining in the clay seams makes the cost of operation quite low.

There are a few quarries on the road from Milton to Limestone Ridge. In one of these which was operated some years ago by Peter Clemmens, the weathered *Stromatopora* bed stands out in excellent relief. This quarry supplied the entire neighborhood and furnished stone for several kilns. It was opened in 1900.

The Milton Borough quarry is along the same line of strike as the Clemmens quarry but higher in the formation. The *Stromatopora* bed is not visible in the former quarry.

There seems to be a regular alternation of massive and thin-bedded limestone throughout the entire region. These shaly limestones separate the darker limestones from the gray. The gray beds are decidedly harder and more massive. The average shaly beds seem to be about 10 inches thick and make up a total of 10 feet. They grade into a powdery yellow rock, which is quite sandy.

Selinsgrove Junction Area. Between Selinsgrove Junction and Sunbury, there is a fine exposure of the Helderberg along the Pennsylvania railroad. Reeside (4, pp. 220-224) has published the following detailed section of this locality.

Section of south side of anticlinal axis north of Selinsgrove Junction

	Thickness in feet
Oriskany formation:	
Sandstone, cherty, fine grained, ferruginous	4.0
Concealed	10.9
Sandstone, cherty, fine grained, ferruginous	7.1
Concealed	
Limestone, dark gray fine grained, very arenaceous; numerous 1-inch chert lentils	12.0
Shale, dark brown	
Limestone, dark gray fine grained, very arenaceous; numerous 1-inch chert lentils	15.0
Shale, very sandy; breaks into flat fragments; dark gray to chocolate-brown	5.4
	54.4
Helderberg limestone	
New Scotland limestone member:	
Limestone, very impure, dark gray, mottled with yellow; weathers into small irregular fragments some of which are siliceous	8.6
Lime shales, dark gray, with a few thin limestone layers; weathers to thin laminae	35.8
Limestone, massive crystalline, arenaceous, dark gray	9.0
Limestone, in large nodules (diameter 6 to 8 inches) embedded in a shaly matrix	4.2
	57.6

	Thickness in feet
Coeymans limestone member:	
Limestone, fairly massive, coarse blue-gray, arenaceous, interbedded with layers of black chert 3 to 4 inches thick; joint planes show large imperfect crystals of calcite and quartz	3.6
	3.6
Keyser limestone member:	
Limestone, thin bedded, (1 to 3 inches), blue, fine grained	5.5
Limestone, blue, fine grained, with conchoidal fracture; courses 6 to 12 inches, separated by about the same thickness of gray calcareous and arenaceous shale	6.9
Shale, yellow	1.4
Limestone, heavy bedded, massive, impure, light gray indistinctly laminated	18.3
Limestone, medium bedded, impure, light gray; a few layers very shaly and weathered; toward upper part the bedding planes weather out clearer and rock is laminated; not distinctly separated from underlying unit	17.1
Limestone, thin bedded (1 to 2 inches); some layers crystalline, pure, blue, fossiliferous; others impure and shaly	3.5
Limestone, finely crystalline, light bluish gray, in two solid beds separated by 8 inches of shaly limestone	3.2
Limestone, pure, fine grained, thin bedded (3 to 8 inches), blue; breaks with conchoidal fracture, though a few layers are platy and impure; layers are separated by thin shale	7.8
Shale, weathered, yellow filled with small lenses of crystalline blue limestone	2.1
Limestone, medium bedded (10 to 12 inches) fine grained blue, with conchoidal fracture; platy in parts; a few fossiliferous lenses	7.8
Limestone, very shaly, light gray to yellow, with a few thin pure streaks	19.8
Limestone in 3 to 6 inch courses separated by about 18 inches of lime shales. The shales are light gray to yellow; the limestones are in part fine grained, in part crystalline. Layer with much pyrite	6.6
Limestone, extremely massive; nodular character not nearly so distinct as in the unit below; coarse crystalline lenses abundant	9.0
Limestone, extremely massive, nodular, dark; nodules pure; matrix earthy, gray; basal 2 feet has in many places a rude columnar structure and is not nodular; upper 2 feet only faintly nodular	13.6
Limestone, impure, nodular; looks sandy but contains no sand	1.2
Limestone, rather heavy bedded, blue-gray, with conchoidal fracture; nodular character pronounced	3.4
Limestone, thin bedded, otherwise like the unit above	3.2
Limestone, very nodular, thin bedded, fine grained, dark gray	4.0
Limestone, very nodular, more or less impure, dark gray. Some benches much more shaly than the remainder and weather back faster. No other bedding noticeable	19.4
Limestone, nodular, dark gray, fine grained; impure looking on fresh fracture; in places inseparable from the unit below, but apparently not a stromatopora bed	3.0
Limestone, made up entirely of stromatoporoids	6.0
Limestone, very nodular, fine grained, thin bedded, bluish gray. Bryozoa throughout	6.0
Limestone, single bed, dark gray, fine grained with conchoidal fracture; very distinct along exposure; not nodular	.9
Limestone, thin bedded, dark gray, nodular, impure	2.5
Limestone, massive, blue-gray, somewhat nodular; bounded where measured by prominent bedding planes	6.0
Limestone, thin bedded (1-inch courses), with shaly laminae between the layers; very nodular. Some layers dense, bluish gray, conchoidal; others sub-crystalline; others earthy	15.1
Limestone, like the unit above but somewhat less nodular	5.2
Limestone like the above two units but less nodular still	3.8
	202.3
Tonoloway limestones	
Limestone, massive, dark gray, conchoidal, fine grained; quarried for lime	4.8
Limestone, thin bedded, medium gray, fine grained, with conchoidal fracture; quarried	3.0
Limestone, solid, dark gray, with conchoidal fracture; quarried just behind some old limekilns by a long cavelike opening	8.2
Concealed	4.0
Limestone, banded, dark impure; has a very noticeable rude columnar structure	14.4
Limestone, dark gray, fissile, banded; contains large geodal calcite masses. In some parts a fine reticulated structure weathers out, due perhaps to silicification along close joints	17.0
Limestone, light gray, siliceous, knotty	1.0
Limestone, rather platy, crystalline, light gray; many stringers and spots of calcite and some small geodes; weathers to thin laminae	10.0
Limestone, fairly pure, dark gray, fine grained conchoidal; in thin lenses separated by very shaly impure layers	6.5

	Thickness in feet
Limestone, very light gray to yellow; impure; conchoidal fracture; apparently not much weathered	3.0
Limestone, oolitic, siliceous, dark gray	.5
Shale, laminated, light gray; thicker layers very light gray on fresh fracture	11.2
Layer of irregular geodal calcite masses	.5
Shale, laminated, light gray	9.8
Limestone, fairly massive, dark gray, fine grained; conchoidal fracture	8.2
Limestone, platy, dark gray	1.0
Limestone, light gray, knotty	3.0
Limestone, very platy, laminated; light gray on weathered surface; dark, impure, earthy on fresh fracture; some layers finely crystalline	4.8
Limestone, light gray; banded on weathered surface; dark, conchoidal, resinous on fresh fracture; solid bed; very fine grained	3.2
Limestone, mostly concealed by talus	10.0
Limestone, banded, gray; breaks into thin, papery fragments	4.0
Limestone, banded, yellowish	3.5
Shale, yellow, weathered	2.0
Limestone, massive, banded, light gray	6.0
Shale, brown, weathered	1.8
Limestone, blue, sandy-looking, massive; apparently very impure; breaks into irregular fragments	7.0
Concealed to the level of the railroad at the axis of the anticline, about 35 feet	
	148.4

Considerable galena and sphalerite were once found in the Selinsgrove anticline north of Selinsgrove Junction. The occurrence was described by I. C. White (2, pp. 99-100) as follows:

"Lead and zinc have been found in considerable quantity just above the base of the Bossardville (Helderberg) limestone, along the river between Sunbury and Selinsgrove Junction, in Northumberland County.

"The mine is reported to have first been discovered about 40 years ago, and some of the ores shipped east in barrels on the Pennsylvania canal; but as the results were kept secret, no one pursued the matter any further until the past year (1882) when Mr. Doughty of Shamokin undertook a systematic development of the ore.

"The mine now being developed comes at the very crest of the Selinsgrove arch, near the 135th mile-post on the N. C. R. R., and the ore occurs about 10 feet above the base of the Bossardville limestone. It occurs in "stings" and "pots," mixed with a large amount of muddy rubbish much resembling the deposits from a stream of turbid water flowing among rocks.

"The course of the deposit appears to run with the strike of the beds, which is here nearly east and west; though the ore has not been followed into the hill far enough to determine much about its extent or manner of deposition.

"Several tons of ore lay on the dump when I visited the mine, and from pieces selected at random Mr. McCreath made the following analysis:

Metallic lead	24.191
Metallic zinc	31.954
Metallic copper	1.389

"Both the lead and zinc occur chiefly as sulphides, while the copper is in the form of carbonate.

"From this analysis it is plain that Mr. Doughty will have a valuable mine if he can find the ore in sufficient quantity."

Dalmatia Area. This area of limestone is lenticular in shape, outcropping in a valley about three-quarters of a mile wide and six miles long. The limestone crops out in an almost east-west direction for about six miles. It is the eastern end of a canoe-shaped structure. About half a mile north and across the mountain there is a somewhat similar outcrop of the Helderberg but it is of lesser dimensions.

In the second strip are located the quarries of Heber and Urban, but these were not in operation when visited.

About half a mile north of the town of Dalmatia, formerly called Georgetown, is the abandoned quarry of Elmer Radel. The growth of weeds shows that it has not been used for some time. In this quarry, however, the northern flank of the anticline is seen. The rocks are buff to blue, and rather impure. The beds are somewhat massive and are about 40 feet thick. Here again the so-called "Bastard limestone" of White appears. It is 30 feet thick.

Between Dalmatia and Hickory Corners there are several abandoned quarries most of which are brush grown and contain abandoned kilns. The quarries of a Mr. Long, William Phillips and one other, the owner of which could not be ascertained, are on the southern flank of the anticline. The quarry of Elias Phillips is across the valley on the north side and has been abandoned.

The largest abandoned operation seen in the valley is the old quarry which was worked by Mr. Sieman and Philip Klinger. It is on the north side of the valley and is about 500 feet long in an east-west direction. At the extreme western end of the quarry the beds dip 75° from the Dalmatia axis. Due to the tremendous shattering along the axis the beds appear to be quite thin. They are weathered to a dull yellow. These beds are about 25 feet thick and abound with poorly preserved fossil forms.

Above this band of shattered limestone there are prominent veins of pure white calcite which can be traced some distance. Several fossil zones, including the *Chonetes jerseyensis* zone, were found.

About two feet above the last fossil horizon there is a rather gnarly bed of limestone which breaks into angular pieces, and which is scantily fossiliferous. The *Chonetes jerseyensis* zone and the *Stromatopora* bed of the Keyser are exposed in this abandoned working. To the east the calcite veins lose their parallelism and their characteristic cross-cutting. Ruins of twelve kilns are on the property.

Many small operators were at work in the Dalmatia area when the region was visited.

On the road to Mandata (Bull Run), across the valley and beyond the schoolhouse on the right side of the road, is the quarry of Mr. Hepner. About a quarter of a mile farther east there is another Hepner quarry. Both of these quarries have been worked along the strike and show the thickness of the good limestone to be about 40 feet. The beds here dip about 53°NW and strike N82°E. The strata at the western end of the quarry are gray and have numerous calcite veins. This limestone is underlain by a grayer limestone which is more massive and contains many calcite veins. Some purple fluorite was found here. Some of the upper beds show graphitic slickensided surfaces.

Along the southern end of the quarry there is a broad, flat face of black limestone which also shows excellent slickensided surfaces. This

marks the contact of the Keyser and the Tonoloway formations. It is a distinct contact. This particular quarry is operated by Edward Hepner and was formerly the property of Gabriel Adams, who opened it in 1842. Mr. Hepner has burned about 2,500 bushels of lime a month.

About a quarter of a mile farther north along the road to Mandata is the quarry of the elder Hepner. It is in the same ridge as the Urban quarries and along the same line of strike as the other Hepner quarry. It shows practically the same features as the former except that the rock tends to become more massive and breaks with a characteristic glassy fracture. The elder Hepner was intending to install a pulverizer.

The Dalmatia axis crosses the Pennsylvania Railroad (Northern Central Division) north of the town of Dalmatia. It is one of the type localities chosen by Reeside (4, pp. 217-220).

Section 1 mile south of Dalmatia

	Thickness in feet
Helderberg limestone:	
New Scotland limestone member:	
Concealed by wash, filled with yellow-brown ochery shale and much chert	6.4
Shale, ochery yellow, fissile, fine grained	1.5
Concealed interval; clay and soil filled with fragments of weathered brown ochery shale and sandstone; a little chert observed	13.7
	21.6
Coeymans limestone member:	
Limestone, coarse, dark gray, very sandy; weathers to resemble a brown ferruginous sandstone; contains black chert lentils; no fossils observed	2.0
	2.0
Keyser limestone member:	
Limestone, banded, fine grained, with conchoidal fracture, in 2 to 4 inch layers, separated by same thickness of weathered yellow shale; contains near top some large, irregular curly masses (18 inches in diameter), which look somewhat like *Stromatopora*	10.3
Limestone, blue gray, conchoidal fine grained, in four layers (8, 10, 3, 10 inches) separated by platy yellowish limestone	3.3
Limestone, banded, fine grained, extremely platy, yellow on weathered surface, light gray on fresh fracture; calcite seam at top	5.7
Limestone, blue-gray, fine grained, conchoidal, thin bedded (6 inches); scattered lentils of black chert (1 inch thick and 18 inches long; calcite sheets	2.9
Limestone, bluish, fine grained; conchoidal fracture; in thin layers (1 to 3 inches), with shale laminae between; calcite sheets	12.1
Limestone, very impure, dark, shaly; carries irregular lenses (2 to 3 inches in diameter) of pure bluish limestone; in bulk about half of each; weathers to a light-gray color; calcite seam near base and at top	6.0
Limestone, pure, thin bedded, fine grained, bluish gray; conchoidal fracture; some fossiliferous lenses	1.7
Limestone, coarse, blue-gray, crystalline, in irregular 2 to 3 inch layers with light gray shale laminae between; calcite sheet near top	3.2
Limestone, shaly, weathered, impure, dark gray; contains a few pure crystalline streaks; calcite sheet near top	1.9
Limestone, coarse, crystalline, bluish gray, profusely fossiliferous	0.4
Limestone, solid, impure, dark gray; weathers yellow, contains many streaks of pure fine-grained limestone; calcite sheet at top	2.0
Limestone, coarse, crystalline, blue-gray; weathers light gray; profusely fossiliferous	2.3
Limestone, impure, medium gray, fine grained; weathers brown and has a number of thin conchoidal purer lenses which weather light gray; calcite sheet at base; solid unit as a whole	3.9
Limestone, blue, crystalline, in lenses 1 to 2 inches thick, with irregular shaly layers between; shale weathers yellow; limestone gray	2.2
Limestone, in four layers; blue, conchoidal, fine grained; crystalline fossiliferous streak; shale laminae between layers	2.5
Shale, calcareous; light gray and yellow on weathered surface, dark gray on fresh fracture; has a diagonal "shear" parting and is interleaved with numerous thin beds of pure blue-gray crystalline limestone	4.0
Limestone, solid, blue, fine grained; conchoidal fracture; apparently very pure; calcite sheets at top, at base and in middle	2.6

	Thickness in feet
Shale, calcareous; light gray and yellow on weathered surface, dark on fresh fracture	6.5
Limestone, solid but impure; dark gray and fine grained on fresh fracture, but very light gray and yellow on weathered surfaces; calcite seam at top with a slickensided surface	3.0
Shale, calcareous, very platy and papery; weathers yellowish and light gray; contains a number of solid but impure limestone layers (2 to 6 inches thick); shaly parts show much diagonal "shear" parting	7.5
Shale, calcareous, light gray, with diagonal "shear" parting	.5
Limestone, massive, somewhat nodular, impure, dark gray, with several crystalline, fossiliferous seams	3.9
Limestone, single layer, finely crystalline, light bluish; conchoidal fracture; calcite seam at top	.3
Limestone, massive, somewhat nodular, impure, dark gray, with several crystalline fossiliferous seams	4.0
Limetone, single layer, finely crystalline, light bluish; conchoidal fracture; ½ inch calcite seam at top	.4
Limestone, massive, dark gray, crystalline, not distinctly nodular; fossils show on weathered surface sparingly	2.2
Limestone, massive, nodular, impure, dark gray, coarsely crystalline layers; calcite seams persistent parallel to bedding	8.1
Limestone, massive, nodular, impure, medium gray; nodules pure, matrix impure and shaly. *Favosites*, in large heads, abundant in lower 7 feet	12.8
Limestone, massive, nodular, impure, much like unit above, calcite seams	12.3
Limestone, massive, nodular, dark gray, impure; ½ inch seam of calcite at base; when weathered looks thin bedded	5.8
Limestone, massive, nodular, dark gray; conchoidal fracture	5.5
	139.8

Tonoloway limestone:

Limestone, dark gray, pure, crystalline; solid bed; shows a rude columnar character in places; has everywhere one or two ½ inch calcite seams at base	3.2
Limestone, thin bedded (1 to 3 inches); beds do not seem to separate, and unit looks rather massive, dark gray fine grained, conchoidal in part; crystalline in part; very pure	20.4
Limestone, thin bedded (3 to 6 inches), dark gray, in part coarsely crystalline	1.7
Limestone, massive, dark gray, crystalline	4.7
Limestone, impure-looking, dark gray, banded; much very fine, disseminated pyrite; purer than the next lower unit	2.5
Limestone, impure, gritty-looking, dark gray, with a pronounced diagonal parting; looks as if it had been sheared	3.6
Limestone, massive, banded, pure, dark gray; shows columnar structure	2.4
Limestone, shaly, dirty gray; irregular, diagonal "shear" parting; 1 inch of calcite at base	.6
Limestone, massive, banded, pure, gray; shows columnar structure in places	4.7
Limestone, alternating shaly and pure in 1-inch courses	.9
Limestone, massive, dark gray, pure, banded	.8
Limestone, same, not banded	.6
Limestone, massive, dark gray, pure, banded	1.7
Limestone, dirty gray, sandy-looking but contains no sand; shows everywhere an irregular diagonal parting as if it had been sheared	.7
Limestone, pure, platy, dark gray	1.0
Limestone, very massive, blue-gray; shows no banding	3.2
Limestone, pure, very platy, laminated; has some geodal calcite layers; shows distinct rude columnar structure in places	6.9
Limestone, pure, dark gray, fine grained; conchoidal fracture	1.0
Limestone, pure, dark gray, very platy and laminated	1.0
Limestone, light gray, fine grained; conchoidal fracture; has black layers which mottle its fracture surfaces	.8
Limestone, platy, dark, impure, passing into weathered yellow calcareous shale above	3.2
Limestone, pure, thin bedded (3 to 6 inches) blue gray	1.0
Shale, calcareous, weathered, yellow, with some geodal calcite layers and several thin limestone streaks	6.7
Limestone, fairly pure, but thin bedded and platy	6.2
Limestone, impure, banded, platy, light gray; curly layer near base contains small radiating masses of strontianite	2.2
Shale, weathered, yellow	.6
Limestone, curly, dull gray, fine grained, with much disseminated pyrite	.2
Limestone, heavy, blue-gray, pure, fine grained; shows some banding	3.0
Limestone, impure, shaly-looking; weathers into thin laminae; perhaps a little purer in middle 3 feet	12.0
Limestone, purer, dark gray, thin bedded (1 to 2 in.)	.9
Limestone, impure, shaly, dark gray	1.5
Limestone, fairly pure, dark gray, thin bedded (1 to 2 inches)	2.5
	102.4

The Susquehanna Stone Company, trading under the name of the Williamsport Stone Company, has a large quarry at Stone Crusher, on the east bank of Susquehanna River between Dalmatia and the Dauphin-Northumberland County line. The Oriskany formation which borders the railroad has been cut through and the underlying Helderberg exposed.

The blue-black limestone, forming the base of the quarry, is slaty and is probable Tonoloway. It is regarded as a slate by the men and is not worked. The thickness could not be estimated because of the covering of debris. The sequence above the blue-black limestone is: a thin limestone, a thin layer of calcite, a 41-inch bed which is badly shattered, a harder gray limestone 25 feet thick composed of beds that average from two to eight inches in thickness. These beds die out to the east. Over them is another bed which may be distinguished by means of large nodular pieces of limestone, some of which are more than a foot in diameter. Below them the rock changes and much calcite vein material appears.

The quarry is worked in benches to which the men gain access by ropes and from which the large stones are thrown to the quarry floor thus breaking them up.

OTHER LIMESTONES

Tully limestone. The Tully limestone, 60 feet in thickness, has been reported from Rush Township and probably occurs elsewhere in the county. It is too impure to be of value.

Hamilton-Marcellus limestones. South of Selinsgrove Junction, White (2, p. 360) has given the following partial section:

Partial section of Hamilton-Marcellus limestones south of Selinsgrove

		Feet
Hamilton:		
Dark shales and slates often exhibiting cleavage and much weathered so that the bedding planes can only occasionally be made out when the dip is S10°E. about 20°, exposed along N. C. R. R. to Water Tank at mouth of Little Run, opposite the middle of Clark's island or a distance of 2100′ along the R. R.; thickness cannot be far from		600
Selinsgrove Upper limestone:		
(a) Light gray limestone impure with dull fracture containing *Ambocaelia umbonata* and *Aulopora tubiformis*	10	
(b) Drab, limy shales	20	40
(c) Shaly impure limestones containing *A. tubiformis* and other fossils in a very fragmentary condition	10	
Marcellus:		
Marcellus shale, very black fissile slate with *Leiorhynchus limitare* and *Styliola fissurella* in its upper half, no fossils observed in the lower		305
Selinsgrove Lower limestone, hard, light gray limestone, somewhat impure in layers 1 to 3 feet thick interstratified with thin layers of gray shale, containing at 15 feet above base large numbers of *Ambocoelia umbonata* and *Leptocoelia acutiplicata*, and in less numbers *Strophomena rhomboidalis*, *Pleurotomaria* sp? *Zaphrentis* sp?; thickness		65

Selinsgrove shale, a light-gray shale, weathering into splintery-like pieces, and having a few thin layers of impure limestone in the uppermost 35 feet; no fossils seen; thickness down to top of *Oriskany limestone* in bed of Susquehanna river 140

There is considerable doubt whether these limestones belong to the Hamilton and Marcellus as given above. E. M. Kindle (3) has identified the Selinsgrove Lower limestone as the Onondaga and this conclusion is also held by Bradford Willard (6). Economically they are of little significance and so far as known have never been quarried. These limestones are finely exposed in some new road cuts at Selinsgrove Junction. They are dark gray to black, with occasional black shales and without chert.

Salina limestones. Some shaly impure limestones interbedded with shales that occur in Northumberland County have been referred to the Upper Salina group. It is believed that in part they may belong to the Tonoloway. They are of little, if any, economic value.

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PERRY COUNTY

Perry County is fairly well supplied with limestone, as it is present in fourteen of the twenty townships of the county. The only ones that seem to lack outcropping limestone beds are Juniata, Wheatfield, Penn, and Rye on the west side of Juniata River and Howe and Buffalo on the east side.

Practically all of the limestones represented in the county belong to the Helderberg (including Tonoloway) group although the Onondaga group also contains some limestone lenses, one of which, located in the left bank of Juniata River at Half Falls Mountain, has been quarried in recent years.

The Helderberg limestones of the county have been quarried in scores of places. As in other counties of the State, the first use made of them was for agricultural lime. At one time it seems that the majority of the farmers used local lime on their farms and almost all that had limestone on their properties quarried and burned their own lime and sold either stone or lime to their nearby neighbors not so favorably supplied. This industry has now declined greatly and abandoned lime kilns can be found in many places. However, the industry is not dead, as lime is still being produced, but it is mainly in the hands of men or companies who make it their chief business and sell the lime to farmers over a larger area. The improvement in the roads and the increased cost of farm labor have brought about these changes.

The most important use at present for the limestones of the county is as crushed stone for improved highways and in general concrete construction. A number of concrete and macadam roads have been built during the last few years and practically all material has been supplied by local quarries. At present one firm with several quarries in different parts of the county is supplying nearly all the crushed stone needed and is selling some for roads in neighboring counties. This concentration has resulted in increased efficiency.

HELDERBERG LIMESTONES

The eroded folds that traverse Perry County northeast to southwest or in places almost in an east-west direction are responsible for the numerous outcropping bands of Helderberg (including Tonoloway) limestone that weave back and forth throughout the county.

The most northerly band of the Helderberg enters Perry County from Juniata County in Greenwood Township, northeast of Juniata River. It continues east on the south side of Turkey Ridge to within about four miles of Susquehanna River where it loops back and follows westward along the north side of Wildcat Ridge to Millerstown. These two bands are the sides of an anticlinal fold that has been eroded to form Pfoutz Valley.

The band with several plications or minor folds continues southwestward in Raccoon Valley to Ickesburg where several folds just east of the town result in a wide band. From Ickesburg the limestone continues southwesterly, passing just north of Kistler and Blain, almost to New Germantown. It then bends eastward, passing a short distance north of Andersonburg and New Bloomfield, and crosses Juniata River

in the northwest corner of Watts Township. Limestone Ridge of Saville, Centre, Oliver, and Miller townships is formed by these limestones. Again turning westward, it passes through New Bloomfield and westward near Elliottsburg and Green Park. It then makes a number of short loops back and forth carrying it southward to the vicinity of Landisburg and still farther southward to Falling Springs and Green Valley. From the latter point, it continues eastward between Little and Blue Mountains, but has not been traced as far as Susquehanna River. Everywhere minor anticlinal and synclinal folds have complicated the major structures and brought the strata to the surface in places where they would otherwise not appear.

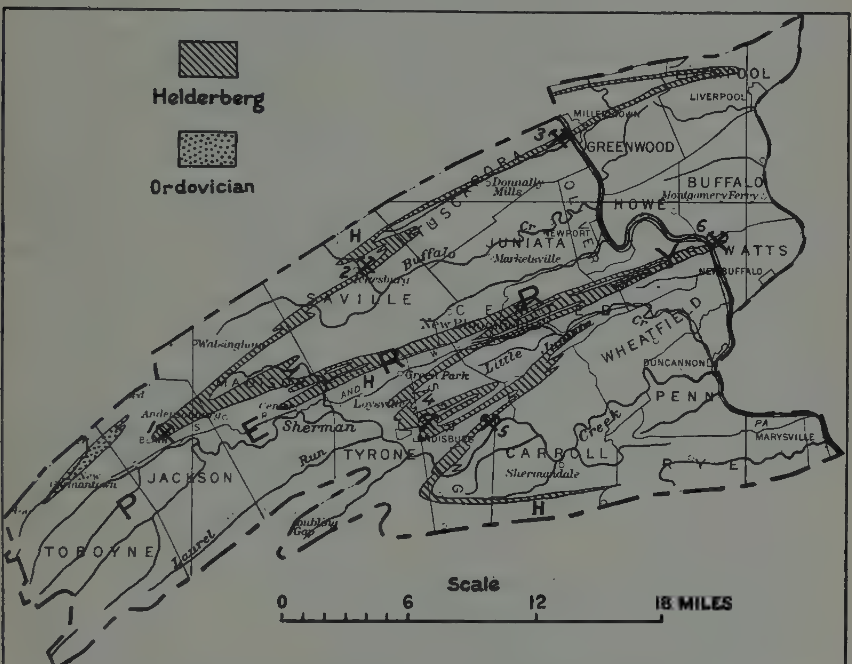

Fig. 31. Limestone areas in Perry County.

1, 2, 4, 5. Dyson and Rice. 3. M. C. Hockenberry. 6. Ira Gowe.

The Helderberg limestones weather more readily than the sandstones and less readily than the shales with which they are associated. Accordingly we find the limestones forming minor ridges in most places, with the shales underlying the bottoms of the valleys and the sandstones forming the principal mountains. This feature has made possible the opening of hillside quarries in proximity to the main highways which generally follow the shale valleys.

It is not practicable to attempt a detailed description of all the exposures of the Helderberg limestones within the county nor even of all the quarries that have been worked at one time or another as they are entirely too numerous. The following areas which include all of the regions where quarries were in operation in 1931, as well as some others, indicate the character of the stone and its adaptabilities.

DESCRIPTION BY DISTRICTS

Blain Area. The Helderberg limestone forms a low ridge that runs through the valley a short distance north of the small village of Blain. Several quarries have been worked at one time or another in the vicinity of the town. The earliest ones were worked for stone to be burned for lime but in recent years the stone quarried has all been used for highway purposes. In 1931, the only quarry in operation was that of Dyson and Rice, located about half a mile northwest of Blain. The quarry face is semicircular, about 175 feet long and 75 feet high. It is worked in two benches and is being driven eastward along the strike. The upper bench, about 20 feet high, shows rather badly weathered, somewhat shaly stone. The strata are folded into a fine anticline and a syncline. This upper portion contains the persistent bed of *Stromatopora* corals which is about 6 inches thick. Many of the corals project from the weathered surface, giving the rock a nodular appearance. The individual coral heads are 1 to 6 inches in diameter and give a fetid odor when struck. The lower bench, 55 feet thick, contains massive beds, 8 to 10 feet thick, of dark-colored limestone. Some of the stone is brittle, breaking with a glassy fracture, and other portions are tough and gnarly and well suited for crushed stone. There is very little shaly stone. One layer shows prominent sun cracks which cause the bed to break into columns. Ripple marks are also prominent. Calcite veins are present, but not common. A few of these calcite veins contain some fluorite. A shallow synclinal fold is well shown in this lower bench. This quarry has furnished a large amount of good road stone in recent years. The production in 1931 was about 40,000 tons.

The outcrop may be traced across the hill for a distance of half a mile where the rock is again exposed in the abandoned McVey quarry.

Section exposed in the McVey Quarry

	Feet
Keyser limestone:	
Upper, shaly and platy limestone	15
Bluish limestone, weathers yellow	10
Slaty, ledge, with fossils poorly preserved	1
Hard, siliceous, blue limestone	25
Chocolate-colored limestone	3
Hard, shelly, blue limestone	2
Soft, blue limestone, crumbles easily	1
Blue, thin-bedded, limestone	3
Tonoloway limestone:	
Thin-bedded and platy limestone	20

Ickesburg Area. The Helderberg limestone has been little worked between Blain and Ickesburg. Dyson and Rice have a quarry for road stone about half a mile northeast of Ickesburg. It is opened in the west nose of a rather prominent hill. The beds, which are very regular, have an east-west strike and dip 32° north. The quarry is semi-circular with a diameter of about 150 feet. The face is about 60 feet high at the highest point. The stone is dark blue to black when fresh but weathered surfaces are white or light dirty yellowish-gray. In the quarry, the stone appears to be massively bedded, but on close examination is seen to be very finely laminated. The stone readily breaks along these laminae but in crushing it there are fewer

thin pieces than one might expect. Numerous small stylolites cut across the beds and also occasional thin shale streaks that appear to be mud-filled shrinkage cracks. Some of these shale streaks cut through beds as much as 1½ feet thick. They are irregular and vary in width up to one-eighth inch. There are very few fossils. A few thin layers are rich in *ostracod* remains. The surface weathered and rotten rock overburden which must be discarded is not heavy. Clay pockets are not common but one clay-filled crack extends downward to a depth of 50 feet. During part of 1931 this quarry was operated continuously, producing about 350 tons of crushed stone per 24-hour day. It seems that the production for the year was about 20,000 tons.

Millerstown Area. Although the same northern band of Helderberg limestone continues northeastward through Raccoon Valley there has been little recent quarrying between Ickesburg and Millerstown. In the hill lying between the main highway and Raccoon Creek, M. C. Hockenberry was operating a small quarry about three-fourths mile west of Millerstown during the summer of 1931. The stone worked consists of thin-bedded limestone considerably broken by frost action. The beds dip south into the ridge at an angle of 40° to 50°, making quarrying difficult and expensive as some of the overlying beds are of poor quality. The drilling is done by hand. The stone is burned in a small kiln near the quarry and sold for agricultural lime. There are few fossils in the rock, although some large *ostracods* were noted.

Pfoutz Valley Area. The Helderberg limestones are present along both sides of Pfoutz Valley, dipping southward under Wildcat Ridge and northward under Turkey Ridge. This area lies in Liverpool Township and when visited contained no working quarries. The State Highway Department once operated a quarry at the head of the valley in Liverpool Township in order to secure stone for the construction of the State highway from Millerstown to Liverpool.

Section exposed in quarry in Liverpool Township

	Feet
Overburden	6
Shattered limestone, no bedding visible	9
Bluish to black massive limestone	8
Thin yellowish shale 2 inches	
Homogeneous limestone, beds one to ten inches	10
Thin-bedded, bluish limestone with fossils	12
Numerous veins of calcite with fluorite at base	

The quarry is about 200 feet long and there is much evidence of cave formation to the east, and much shattering to the west where the rocks pitch steeply into the hill.

Northwest of the quarry the rocks form the northern flank of the anticlinal valley and pitch under Turkey Ridge. Here are located the abandoned quarries of Messrs. Parner, Rumbaugh and Kaufman. Mr. Parner stated that owing to the ease with which lime could be secured from the Dalmatia area, the quarries in this district have never been extensively worked. Due to the shallow depth of the quarries, the weathered stone is very prominent and appears to be of low grade. It is generally thin-bedded, but better stone would be encountered at

depth. The Parner quarries showed considerable calcite vein material in the lower beds.

The upper limit of the Helderberg along the southern border of the valley may be mapped because of an outcrop of chert along the northern flank of Wildcat Ridge.

Generalized section of the Helderberg limestones of Pfoutz Valley

	Feet
Blue to blackish limestone, massive	2.0
Yellowish shaly materials	0.5
Fossiliferous, massive, blue limestone	12.0
Thin-bedded, bluish limestone	15.0
Dark blue limestone with veins of calcite, and some fluorite forming the base of the quarries	20.0

Most of the stone that has been quarried in Pfoutz Valley was burned for agricultural lime. At one of the quarries east of Nekoda some raw stone was once pulverized for agricultural use.

Landisburg Area. North and east of Landisburg, the Helderberg, due to several parallel folds, is prominently developed at the top of several hills. The largest quarry and the only one operating during the summer of 1931 is that of Dyson and Rice located less than half a mile north of Landisburg. The quarry, which is almost circular, has a working face of about 225 feet with a height of 65 feet. The strata have gentle rolls but in places are almost flat. There is a thickness of clay and rotten stone from 15 to 18 feet thick which must be stripped and wasted. The stone has been burned for agricultural lime and pulverized raw for fertilizing purposes but more recently the entire product has been crushed stone for highway use. The annual production is about 35,000 tons. The layer of *Stromatopora* corals so common throughout the county is about 8 feet thick near the center of the section. Beneath it is a thickness of about 8 feet of stone that yielded a good grade of lime. It contains many gash veins of calcite. An enormous amount of stone, easily obtainable, is available in this section.

New Bloomfield Area. Because of the great amount of folding, the Helderberg limestone covers a great deal of territory to the north of New Bloomfield. The ridge formed by the outcrop is known locally as Limestone Ridge. It includes the excellent Clarks Mill exposure cited by Reeside and quoted below.

In the Harmon quarry, three-quarters of a mile north of the Court House, the following section is exposed:

Section of Helderberg limestone near New Bloomfield

	Feet
Steel gray, rather shaly limestone	10
Blue massive limestone, weathers yellow	15
More or less crumbly limestone	5
Vein of calcite 2 inches	
Bluish limestone, sandy and clayey	2
Hard, siliceous limestone	2
Gray to blue limestone beds two feet thick	11

The quarry is no longer in operation; two kilns in ruins show signs of former activity.

One of the type localities of the Helderberg is about 2 miles northwest of the town along the abandoned Newport & Shermans Valley Railroad. It is one of the best exposures in central Pennsylvania. Although the fossils are abundant, they are not very well preserved and hence are very difficult to identify.

According to Reeside, (4, pp. 215-216) the upper 140 feet comprise the Keyser formation and are apparently the same as those named by Claypole as the Clark's shales.

Section at Clarks Mills, about 2 miles northwest of New Bloomfield

	Thickness in feet
Concealed by residual clay, filled with white blocky chert, fragments of coarse sandstone, and thin, platy, shaly limestone. Immediately above the top of the Keyser weathered *Gypidula* valves and segments of a large crinoid column are abundant and indicate the probable presence of the Coeymans member of the Helderberg.	
Helderberg limestone (Keyser limestone member):	
Limestone, fissile, platy, dark gray; fragments ring when dropped; no chert; fresh surface shows distinct lamination	2.0
Limestone, thin bedded, dark gray, with much interbedded black chert; one layer is about 10 inches thick, compact, bluish gray, with conchoidal fracture	5.8
Limestone, thin bedded, full of crinoid fragments and other fossils, crystalline	1.0
Concealed by talus	2.7
Limestone, thin bedded (1 to 3 inches), a little nodular, bluish gray; some of the layers are compact, with conchoidal fracture; others are subcrystalline, crinoidal, and crammed with fossils; the unit, however, looks homogeneous	20.1
Limestone, thin bedded, blue, crinoidal; subcrystalline, and crammed with fossil fragments	1.5
Concealed	3.0
Limestone, crinoidal, bluish	.5
Concealed	4.7
Limestone, gray, crammed with ramose bryozoa	1.0
Concealed	2.0
Limestone, compact, hard bluish	.5
Concealed	27.6
Limestone, thin bedded, dense, bluish, conchoidal fracture	4.0
Concealed	20.0
Limestone, thin bedded, blue, nodular	5.0
Concealed	4.6
Limestone, very thin bedded, nodular, dark gray	4.2
Concealed	3.0
Limestone, thin bedded, much weathered and stained, debris full of fossils	6.0
Limestone, thin bedded, rather nodular, dark gray; upper 3 feet heavier bedded	9.9
Concealed	3.0
Limestone, thin bedded, very nodular, bluish gray	6.6
Limestone, single heavy bed, compact, dark gray	1.0
	139.7
Tonoloway limestone:	
Limestone, rather massive, dark gray, not nodular	3.0
Limestone, fissile, platy, yellowish, banded; fossils very rare, very different from overlying beds; gives a shingle-like talus; dark gray on fresh fracture	5.9
Limestone, single bed, dark gray	1.0
Limestone, dark gray, separated into 1-inch courses by silicified seams ⅛ inch thick, which stand out a little in relief	2.6
Limestone, single bed, knotty, dark gray; weathers into laminae	3.6
Limestone, platy, shaly; weathers into plates	4.0
Shale, contorted, yellow, partly concealed	4.0
Limestone, knotty, irregular, yet massive	5.0
Concealed	7.5
Limestone, very thin bedded, platy, dark gray	8.6
Limestone, massive bed, dark gray, breaks into thin plates	6.2
Concealed	4.5
Limestone, massive, dark gray, breaks into thin plates	6.0
	61.9

The fossils found in the Clarks Mill area include many forms. Reeside has identified 45 species from this locality.

A number of quarries in the New Bloomfield area were once worked for agricultural lime, for fluxing stone and for building stone, but in recent years there has been little activity. One quarry about 1½ miles northeast of New Bloomfield was worked for crushed stone at one time, but the presence of considerable shaly and rotten stone rendered it less desirable than quarries in other parts of the county.

Falling Springs Area. The most active lime burning plant of Perry County during recent years is that of Dyson and Rice at Falling Springs. The quarry is opened in the side of a hill, is about 125 feet across and has a working face about 52 feet high. The section exposed is as follows:

Section exposed in Dyson and Rice quarry, Falling Springs

	Feet
Thin-bedded shaly limestone	10
Massive dark colored limestone	7
Shaly, badly broken limestone	10
Thick to thin-bedded limestone, *Stromatopora* corals are abundant in upper portion making up a large part of the stone. In part the corals are in limestone matrix, in part surrounded by black shaly material	25

The stone from this quarry is burned for agricultural lime. The production is about 18,000 bushels a year.

ONONDAGA LIMESTONES

The Onondaga formation in Perry County contains some limestone of value although in certain sections it is practically a shale.

The only place where the Onondaga limestone is known to have been worked in Perry County in recent years is along the left bank of Juniata River at the end of Half Falls Mountain in the extreme northwest corner of Watts Township. In the earlier edition of this report, this occurrence was described as Helderberg limestone, but it is now known to be of Onondaga age. During the past 15 years, Ira Gowe has been working a quarry here at intervals and burning the stone for agricultural lime. The limestone exposed in the quarry is about 36 feet thick and consists of black argillaceous limestone interbedded with dark gray limestones in which many veins cut the beds vertically. The gray limestones are probably high in magnesia. The beds show some gentle rolls. The limestone is overlain with a great thickness of Marcellus shale. The quarry is opened on the side of a hill and as it is advanced into the hill, the shale overburden becomes heavier. It therefore appears probable that it will not long remain practicable to continue work at this place. The production during 1930 was about 3,000 tons.

Claypole (2, pp. 260-263) in his report on Perry County describes some similar limestones in Madison Township, which he considers to belong to the Marcellus. It seems that they more properly belong to the Onondaga. His descriptions are quoted as follows.

"This is the most interesting stratum to the geologist which Madison Township affords. Its exposures are here more abundant and more nearly complete than anywhere else, and it is chiefly from this

township that I have collected the evidence, both stratigraphical and palaeontological, which has enabled me to assign its true position.

"The limestone in question has been regarded as the representative of the *Corniferous formation* of the New York series, solely on account of its position at the base of the Marcellus black shale. But no trace of the great deposits of flint which characterize that horizon in New York are found in Perry County. Nor have any Corniferous fossils afforded to the palaeontologist satisfactory evidence of the correspondence of the two strata.

"Several good though partial sections in Madison Township afford valuable stratigraphical evidence in favor of a different opinion. The following are the details of the exposure at Dr. S. M. Tudor's quarry near Centre Mills, where the stone is quarried for building and for burning. It will be seen from the section that the limestone beds here are very solid:

Tudor's Quarry section

	Inches		*Inches*		*Inches*
Limestone	2	Limestone	8	Limestone	6
Dark shale	1	Dark shale	3	Dark shale	3
Limestone	2	Limestone	6	Limestone	6
Dark shale	2	Dark shale	4	Dark shale	3
Limestone	6	Limestone	8	Limestone	8
Dark shale	3	Dark shale	4	Dark shale	1
Limestone	6	Limestone	12	Limestone	12
Dark shale	1	Dark shale	6	Dark shale	1
Limestone	4	Limestone	4	Limestone	..
Dark shale	1	Dark shale	2		
					10 ft. 7 in.

"Here is a series of *fifteen beds of limestone* alternating with *fourteen beds of dark shale* exactly resembling some parts of the Marcellus shale. It is black when wet, but dries to a peculiar reddish tint as do many of the layers in the Marcellus proper. There is no impropriety, therefore, on stratigraphical evidence in referring the whole mass in question to the Marcellus, and this conclusion is corroborated by the presence of Marcellus fossils in several of the lower beds of black shale. The strata at this quarry dip very gently to the N.N.W. at about 2°-5°.

"Another small quarry opened on the adjoining farm of Mr. D. Rice shows the following section:

Rice's Quarry section

	Inches	
Black or dark shale	2	4′ 7″
Limestone	14	
Dark shale	4	
Limestone	4	
Dark shale	5	
Limestone	6	
Dark shale	4	
Limestone	18	

Dip 2°-5° N.N.W.

"Both these sections are in the Marcellus limestone overlying the Marcellus lime shales, and exhibit the limestone in the most solid form in which I have seen it in the county. The decrease in the limestone and relative increase of the shale towards the top is obvious.

"West of Centre Mills is a section of rocks dipping 40° to the north, as follows:

Centre Mills section

	Ft.	in.
Limestone		
Dark shale and limestone interbedded	12	
Dark shale	4	
Greenish calcareous shales	15	
Greenish smooth shale	6	
Sandy green shale		6
Soft green shale weathering red		6
Flinty oolitic bed square-fracturing, No. 3		2
Green rubbly shale weathering red	3	
Hard flinty bed, oolitic, No. 2		4
Green rubbly shale, weathering red	6	
Dark oolitic hard bed, No. 1		4
Blue clay	1	
Iron ore, slaty, liver colored	2	
ORISKANY SANDSTONE, soft	15	
	65	10

"This section gives the base of the Marcellus lime-shale down to the Oriskany sandstone. It is obvious that the amount of lime rapidly increases upward and the amount of dark shale diminishes. The gray calcareous shale at the base of the group gives place to an alternation of dark shales and limestone, the latter in very solid, hard beds, as shown in the preceding sections. These beds have yielded numerous fossils for an account of which the reader is referred to the volume on the palaeontology."

Doubtless the Onondaga elsewhere in the county may contain some limestone of slight economic value, but at best the limestones of this formation are far less important than those of the Helderberg. Kindle (3) has mentioned several localities where he identified the Onondaga. At Falling Spring it is 25 feet thick and consists of "hard blue argillaceous limestone in layers 8 to 12 inches thick, interbedded with thinner layers of black shale." At the southwest side of New Bloomfield above Clouser's Dam, it is 56 feet thick and consists of "hard bluish-gray argillaceous limestone and interbedded dark gray calcareous shale." Kindle also describes a section of the Onondaga three-fourths mile east of Alinda, containing considerable limestone.

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PHILADELPHIA COUNTY

There are no limestones in Philadelphia County. The entire county is underlain with metamorphic schists and gneisses. Along the Delaware and Schuylkill rivers these ancient crystalline rocks have been deeply buried by alluvial deposits of clay, sand and gravel.

PIKE COUNTY

There are no limestones of any importance in Pike County. Occasional layers of somewhat calcareous beds have been noted but so far as known at no place within the county are there any beds containing a sufficient amount of calcium carbonate to give them any value. Within the Catskill strata that form the surface rocks over almost the entire county, with the exception of a band about 2 miles in width along Delaware River, there are some calcareous breccia in which fragments of rocks of various kinds have been cemented by calcium carbonate. Also within some of the Devonian shales there are abundant calcareous fossil remains—corals, brachiopods, etc.—that contribute an appreciable amount of calcareous material but not sufficient to class them as limestones.

POTTER COUNTY

No limestones of economic importance are known in Potter County. The rocks of the county consist almost exclusively of sandstones, shales, and conglomerates. Franklin Platt mentions the presence of a "limestone" in the Pocono formation at Coudersport which is a "calcareous clay iron stone" (1, p. 77). He also makes the following statement (1, p. 80): "A bed of limestone is reported to crop out in Harrison Township, at the northeast corner of Potter County, and to be burned for agricultural purposes, although poor and ferruginous. According to Mr. Sherwood it lies in the junction layers of the Chemung and Catskill groups;—and it may very probably represent the limestone opened and worked extensively on the Loyalsock, three miles above Forksville, in Sullivan County."

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Schuylkill County is poorly supplied with limestones, although it contains more than are present in most anthracite counties of the State. Little geologic work has been done on these limestones for a long time but it is probable that the distribution as shown on the geologic map of the county, prepared by the Second Geological Survey (2) of Pennsylvania, is fairly accurate. On that map, the Helderberg limestones are shown outcropping in a narrow band that enters from Carbon County about one-fourth mile south of Andreas and continues southwestward on the south side of Lizard Creek to its head, then westward passing a short distance south of Kepner and New Ringgold, through McKeansburg, Orwigsburg and Cressona. About 2 miles beyond Cressona the band turns eastward, passing through Schuylkill Haven and thence almost due east to a point about half a mile northwest of Drehersville. Due to a series of folds, the outcrop makes a series of small loops but has a direction roughly parallel to Pine Creek, a short distance east of this stream. About a mile west of Molino, the outcrop again becomes regular and continues westward through Auburn and Jefferson. It appears a short distance south of Bear Creek and parallel to it and maintains the same relation to Little Swatara Creek and the main Swatara Creek beyond the junction of these two streams. The outcrop lies a short distance south of the Reading Railroad and parallel to it from Auburn to the Lebanon County line.

With this rather long band of limestones cutting entirely across the southern part of the county, it would seem as though they might have been worked more extensively than they have been. Many years ago, these limestones were quarried at a number of places on a small scale and burned for agricultural lime but even then they appear to have been utilized to a smaller extent than in other counties with similar occurrences. So far as known there have been only two active quarry operations in the entire county in recent years. One is near Andreas in the extreme eastern part and the other along the Schuylkill River about one mile east of Schuylkill Haven. It is generally believed that these limestones are of less desirable quality and thinner farther westward but definite evidence for this belief is lacking.

The most eastern quarry now in operation is located about one-fourth mile south of Andreas. It is now leased by Rudolph and Delano who are quarrying stone for township roads now being improved by the State. The property was long owned in common by a number of farmers, who quarried stone here and hauled it to their farms for burning lime. The entire quarry property is now owned by John F. Horn, Jr. The quarry is opened where the Helderberg limestone forms an anticlinal fold, with the Oriskany sandstone appearing to the south much more prominently than to the north. Normally throughout the region the Helderberg limestones dip northward beneath the Oriskany sandstone.

In the quarry the upper beds, which are more massive except where badly weathered, form a fairly symmetrical low arch. The underlying beds are thinner and have been crumpled into complicated sharp folds. In places the stone has been badly shattered. There are

several varieties of stone in the quarry. One prominent type is a gnarly stone in which nodular masses of dense grayish-blue limestone are separated by thin shaly coatings. There are some thin light greenish shale layers in which there is only a very small amount of calcareous matter. A dark colored thinly bedded stone is highest in lime and was long worked most extensively for that reason. Veins containing white calcite and aragonite, pinkish dolomite, and clear quartz are fairly abundant.

The quarry is about 250 feet long, 150 feet wide and the face is about 100 feet in height. The overburden of talus and rotted rock is heavy. When visited in January, 1932, the quarry was being used solely for crushed stone, producing about 300 tons per day.

A. H. German has two lime kilns near the quarry and burned some lime in 1931 and will probably burn again to supply the local demand for agricultural lime.

Across a small tributary stream to the east, there is an abandoned limestone quarry that has furnished considerable stone for burning. Because of the heavy overburden, a thickness of about 15 feet of the best stone was followed into the hill along the strike in a short tunnel.

The quarry near Schuylkill Haven is operated by Joseph C. Dallago. A number of years ago a small amount of stone was quarried here and burned for lime. About the year 1926, Mr. Dallago opened a small quarry for crushed stone and has been operating more or less continuously ever since. The product has been used on the highways and in concrete construction. The operation is a small one. The crusher has a capacity of approximately 50 tons per day.

The Helderberg at this point is only about 35 feet thick and overlain by Oriskany sandstones and underlain by the Clinton red shales, both formations of which are well exposed. Of the entire thickness of the Helderberg, only about 12 feet of the limestones are being utilized. These beds consist of thin-bedded limestone with some thin shale layers and shale partings. The underlying Helderberg appears to be much more shaly, although there is one rather massive bed one foot thick.

The beds strike N78°W and dip 24°SW in the floor of the quarry now being worked. A short distance back the dip increases almost to vertical.

Only a very limited output can be obtained due to the thinness of the workable stone. By advancing along the strike considerably more material could be obtained but only by removing a rather large amount of overlying Oriskany sandstone. As it is, at one point of the quarry the overlying Oriskany is nearly 18 feet in thickness.

For local use, the quarry is advantageous and the quality of the stone satisfactory, although it can never be expected to furnish any large quantity.

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SNYDER COUNTY

Snyder County is well provided with limestone. Of the 15 townships, only Monroe, Union, and Chapman are deficient. Of these, Monroe and Chapman appear to have the extreme southern tips underlain by limestone, but without outcropping beds.

HELDERBERG LIMESTONES

The Helderberg series of limestones outcrops in three more or less parallel bands that cross the county in a northeast-southwest direction. The most northerly one extends from a short distance south of Centerville, passing near Port Ann, Troxelville and into Mifflin County about a mile north of Bannerville. The beds in this band dip to the southeast at angles of 10° to 50°, constituting the northern limb of a synclinal (trough) fold.

The second band extends from Susquehanna River a short distance north of Selinsgrove westward and southwestward, passing just north of Salem, Meiser Station, Middleburg, Beavertown, Beaver Springs and McClure. In this band the strata dip to the northwest at varying angles. Due to minor folds there are two small isolated areas of the limestones a short distance west of Paxtonville where the largest quarry operation in the county is located.

The third band extends from Susquehanna River a short distance south of Selinsgrove southwestward, passing just south of Kantz, and Freeburg, and north of Mt. Pleasant Mills and Fremont. A minor fold west of Fremont produces three bands for a short distance before the band passes into Juniata County. In this third band the beds dip to the southeast as in the first band.

All of the limestones of the county of any importance belong to the Helderberg series. Thin beds of limestone or limy shales are present in the Salina and Marcellus formations but they are of no value.

Scores of quarries were once worked intermittently on a small scale to supply stone for burning lime for use on the owner's farm. Some stone was quarried for buildings and occasionally for road purposes. The lime industry has been steadily declining, most of the old kilns are in ruins, and yet limestone is still being burned. The chief use in the county is for crushed stone.

The Helderberg (including Tonoloway) strata seem to be more than 300 feet in thickness and contain a number of different varieties of rock. Dense blue to black beds alternate with gray, coarsely crystalline, massive layers and thin bedded to very shaly strata. In places it has been practicable to work only 15 to 20 feet of stone between shaly or siliceous layers of no use. In other places as much as 100 feet of fair grade stone is found with only occasional thin shale partings.

In most places the beds of limestone dip rather steeply as they constitute the flanks of great folds into which all the strata of the region have been deformed. Very locally the beds may be flat or nearly so. The dip of the beds into the hills, which is a common occurrence, limits

the amount of stone readily obtainable without a large amount of stripping. The overburden may be weathered rock with a large amount of the calcium carbonate removed or shaly beds; in either case useless stone that must be removed.

The northerly band of Helderberg limestone has not been worked to any large extent in recent years although at one time there were many small operations, especially between Port Ann and Troxelville. Generally the thickness of desirable stone exposed in these openings is not more than 20 feet.

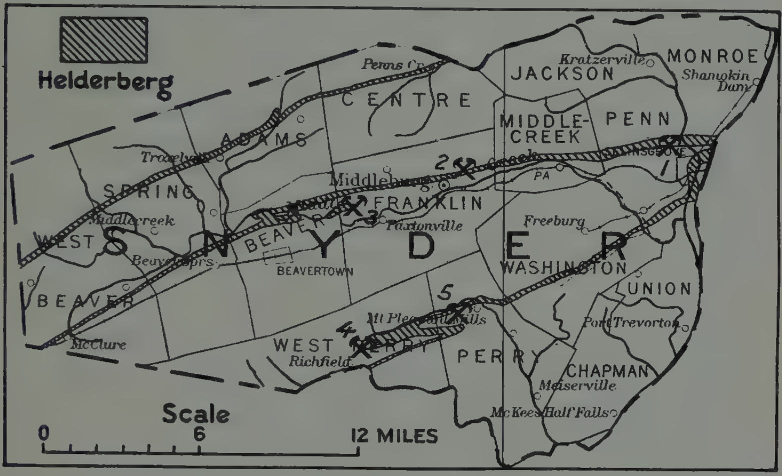

Fig. 32. Limestone areas in Snyder County.

1. Henry I. Romig. 2. Oscar Walter. 3. J. C. Stahl Estate. 4. W. W. Graybill. S. S. Spriggle. 5. Irwin Boyer, H. J. Heim, and Calvin J. Trout.

The most active quarry near Selinsgrove in recent years is that of Henry I. Romig, formerly the Penn Lime and Stone Company, which is about 200 feet long and 60 feet high. Many shale beds are intercalated with the good limestone, making it quite difficult to quarry. A hard siliceous limestone which is difficult to break with the ordinary blow of the hammer runs uniformly through the quarry. In the middle portion, where the elevation is highest, many limy nodules occur. Upon breaking open some of the nodules, which are quite numerous, many fossils were found. These were, however, in such a mutilated state that no identification was attempted. The nodules for the most part are made up of a heavy, hard, gray limestone which is enclosed in a rather impure, bluish limestone, highly fossiliferous. In the west end of the quarry the rock crumbles readily, breaking with a glassy fracture under the least blow. Many clay seams and clay pockets are found. Bedding planes are obscured.

This quarry is said to have been opened in 1861. There are two kilns and a rock crusher. Lime is burned for local use and crushed stone produced whenever there is any demand for the product for highways or concrete structures. The early use was entirely for lime. Several other old abandoned openings are located nearby.

The Helderberg limestone is well exposed along the main highway westward through Middle Creek Valley. Among other places, it is especially well developed in a prominent ridge just north of the high-

way extending from near Kreamer eastward 3 miles. A number of quarries have been opened here but all are now idle. At one place three kilns are still standing and at another place two. Conditions in this ridge are favorable for quarrying.

In the vicinity of Middleburg a great deal of limestone has been quarried in the past. The following descriptions from the geologic report (2, pp. 167-169) published in 1891 give some idea of the importance of the district at that time.

"The Lower Helderberg limestone ridge is not very prominent west of Middleburg until after passing the first gap, about half a mile west of the county seat, and there are no quarries in this part of the range. A shaly limestone outcrops in this gap on a 40°NW. dip and not far beneath No. VII (Oriskany). Between this gap and the next, a distance of one mile, the limestone is pretty well concealed by the chert of No. VII (Oriskany), occasional outcrops on the road, showing 40° north dips.

"John Hassenger's quarry on the eastern side of this gap, shows a dip of N. 12°W. 50°, and has exposed about 60 feet of limestone, in which the good beds are interleaved with inferior ones as follows:

	Feet
Gray blue stone, weathering rough	8
Siliceous white stone; cavernous	4
Good blue beds, smooth grained	8
Thin bedded blue stone, weathering rough but pure	12
Hard blue limestone bed; good quality	6
Thin blue beds, hard and siliceous	6
Massive blue bed, sparingly opened	12
Bluish-gray bed, not well exposed	4

"The Lutheran Church quarry on the west side of the ravine shows the same beds, but not so largely developed. Both furnish good lime for country use and both carry a considerable thickness of sandy lime shales on top, quarried slightly for road purposes, and showing lime shales and thin limestone beds, from 50-60 feet thick. There is an interval between these lime shales and the quarries with a vertical thickness of about 100 feet which may contain good limestone beds. Just before entering Beaver Township the ridge shows a long sloping terrace to the south of a back bone of No. VII (Oriskany) chert, exposing an outcrop of shaly limestone from 60-80 feet thick on a 25° north dip. This gentle dip of course spreads the outcrop; but the No. VI (Lower Helderberg) formation does not seem to be very massive here.

"Smith's quarry is located within the borough limits of Middleburg on the west side of the Centerville road. The rock exposure consists of the upper 30 feet of No. VI (Lower Helderberg) dipping N. 10° W. 40-50°. The "soapstone" band is visible here; but the good beds beneath it are largely covered up with debris and have not been actively worked. The quarry is about 60 feet long; but when seen in August, 1888, was in a frightful condition, the stone having been quarried here and there, without rhyme or reason, and producing a very rough and unattractive appearance in the exposed faces.

"East from Middleburg along the road, the limestone outcrops frequently on a 40°north dip, the road gradually ascending the hill and passing over higher limestone beds.

"J. Walter has opened a small quarry ½ a mile from the county seat and close to the north side of the public road, and exposing about 30 feet of the upper rough beds of the massive portion of the Lower Helderberg formation.

"Phillip Spade has the next quarry, 100 yards east, working the same beds close to the roadside. The quarry has one kiln.

"Kersteller and Bower and N. Walter have kilns adjoining the last party and work practically the same beds on a 40-50° dip.

"Peter Frain has the next kiln, 25 yards along the road, and Hartman & Beachel have a small quarry adjoining him on the east. About 10 yards further along the road Weirich & Ocker own an abandoned kiln. The last three quarries are practically one opening, each party owning about 50 feet along the outcrop.

"J. Arnold lies next east, and there are six additional openings of the same character in the next 200 yards, all exposing about the same beds and worked from time to time for local farm use. These are: 1. Walter Stuck. 2. W. Bailey. 3. J. Shambach. 4. E. Hummel. 5. Musser & Brunner. 6. J. Mitchell.

"Hare, Swineford & Erde own quarries west of Walters, but have no kilns, and their openings look more like side cuts for the passage of the road than like limestone quarries. The entire series of quarries is comprised within a thousand feet of outcrop and much better stone could be obtained by opening between the road and the creek, if facilities existed for getting the product to market. The ridge is cut off on the east by a small stream entering at the mill, and the Lower Helderberg limestone outcrop is largely concealed there by the detritus derived from the broken down Oriskany sandstone ridge."

In 1921, two quarries then in operation in the Middleburg area were described by the author as follows: "There are two quarries in this area, one northeast of the town and the other on the north side of the road leading from Middleburg to Selinsgrove. The first quarry, opened in 1919, is operated by D. J. Stahl. About 25,000 bushels of lime are burned monthly. The crushing equipment includes a Jeffrey crusher and turns out 100 tons of stone per day.

Section in the D. J. Stahl quarry, Middleburg

	Feet
Keyser (lower) limestone:	
Thin-bedded, blue-gray limestone	10
Dark, gnarly, thin-bedded limestone	15
Blue-gray limestone, with no fossils	12
Hard-gray limestone (road material)	

"The quarry face is about 45 feet high with a 100 foot breast. It is operated with compressed air drills and hand sledges. Gravity traction is used to convey the cars to the jaw crusher.

"The quarry along the road to Selinsgrove is owned by Dr. Zechman. The State Highway Department to which it was leased has installed a portable crushing plant."

Section exposed at the Zechman quarry, Middleburg

	Feet
Thin-bedded, shaly, fossiliferous limestone	6.0
Thin streak of gnarly limestone	0.5
Massive limestone	10.0

The Zechman quarry was opened in 1895 and is about 24 feet high and 100 feet long. The output is 200 tons per day.

In 1931 Oscar Walter was operating a quarry on a small scale and burning lime in the ridge northeast of Middleburg.

West of Paxtonville, there are two ridges of Helderberg limestones formed by minor synclinal folds. These two areas are entirely distinct from the band of limestone just described. The larger one, known as Benfer's Ridge, is about 1½ miles long and the other one about half a mile long. The longer ridge of limestone has long been worked. In 1889 it was described as follows (2, p. 170):

"In the larger hill, known locally as Benfer's Ridge, there are four small quarries; two on either side of the public road crossing the ridge and two lying further east towards Middle Creek.

"1. Schoch's quarry is a small abandoned opening where no work has been done for years. It is situated on the east side of the road. on the backbone of the ridge, and exhibits a section of about 20 feet of limestone on a 50°NW. dip, all of it of good quality, except the upper 5 feet, and advantageously located for development.

"2. Benfer's quarry and kiln is immediately opposite Schoch's on the west side of the road; 50 feet long and 30 feet high, exposing about 30 feet of flat dipping limestone right in the trough of the synclinal which is well developed in the west end of the quarry. There are two principal beds, 8 feet and 4 feet thick, separated by one foot of shale; but the larger 8 foot bed on top shows a somewhat vertical cleavage and breaks out in irregular blocks. Above it are 10-15 feet of smaller beds and some shale. A great deal of excellent farm lime is burned here to the extent of about 800 bushels a year, all of which is used locally on Mr. Benfer's property.

"3. Gill's quarry is a side hill cut on the east side of the road near the south base of the ridge and about 150 feet in length. The dip here is fully 40° to the northwest, although but a short distance from the two before mentioned quarries, and is developed in lower beds. About 40 feet of gray and somewhat discolored limestone is exposed here, generally in thin and somewhat shaly beds.

"4. Smith's quarry is the last opening near the eastern end of the ridge, developing only a few feet of stone in the center of the synclinal on the summit of the hill."

At present the largest quarry in the county is operated in Benfer's Ridge about one mile west of Paxtonville by the J. C. Stahl Estate. The quarry is located at the crest of the ridge and is about 200 feet wide (north-south) and somewhat longer in an east-west direction. The face is from 90 to 95 feet high and is being advanced westward. The beds are mainly quite massive up to 4 feet in thickness and there is very little interbedded shaly matter. The rock is gray to black in color and of good quality. Some fluorite is associated with the calcite in the occasional veins that cut the beds. The beds are almost horizontal. The overburden of soil and rotten rock varies from 3 to 5 feet in thickness. Conditions are very favorable for quarrying and a large output is possible. When visited about 500 tons of crushed stone were being produced daily and this could be increased.

The drilling is done by well drills, the stone loaded by steam shovel and hauled to the crushing plant. The company has three steam shovels. The stone is first broken by a large jaw crusher and passed over a screen to remove the fine material which is discarded as it contains some earth and rotten stone. The product next goes to a large gyratory crusher, is then screened and the large stones crushed in secondary gyratory crushers. To secure especially clean stone for concrete, the product is washed in a log washer. The water is partly supplied by a small stream that disappears in a sink near the plant, partly by water from the mountain to the south and partly from a deep well.

The company has installed a Williams hammer mill pulverizer and has pulverized some stone to 16-20 mesh size for farm use. The farmers in the vicinity have been experimenting with the product and it is hoped that they may become convinced of its value.

In the southern band of Helderberg limestone crossing the county, quarries have been opened all the way from the south side of Selinsgrove to Richfield. The strata in most places dip to the south into the hill. The most active quarrying has been carried on along the north slope of Lime Ridge which begins about one mile north of Richfield and extends in a northeasterly direction to Fremont (Mt. Pleasant Mills P. O.) a distance of five miles. Occasional quarries have been opened along the band eastward to Selinsgrove.

During 1931 there were two active quarries in the west end of Lime Ridge about a mile north of Richfield. W. W. Graybill was working a small quarry containing some good grade dark-colored stone which becomes white on weathering and containing few fossils and some gnarly fossiliferous rock. About 20 feet of stone is being quarried. The beds dip north at an angle of about 50°. The stone is burned for agricultural lime in 2 kilns. A short distance to the north S. S. Spriggle was working stone to supply one kiln. Here the beds dip to the south at an angle of about 40°. Several different kinds of stone are exposed in the quarry including some gray tough stones of good quality, some thin-bedded black limestones containing some interbedded shale laminae, and some black, more massive beds of good quality which break with a prominent glassy fracture. The overburden of rotten rock and talus are serious obstacles.

About midway of Lime Ridge a Mr. Pile has recently worked a small quarry in which from 12-15 feet of massively bedded stone of good quality is underlain and overlain by beds of poor stone. The strata dip into the hill at angles of 35° to 40°.

On the north side of Lime Ridge just west of the place where Mahantango Creek cuts the ridge at Fremont, there is a great series of old quarries that were mainly worked for limestone for agricultural lime but to a smaller extent for crushed stone. The strata dip southeastward into the hill at angles of 50-60°. These quarries show both good and poor stone. As work is continued in this region, the overburden of rotten and poor rock increases so that it becomes increasingly expensive to obtain good stone for burning. Irwin Boyer, H. J. Heim, and Calvin J. Trout were all operating and burning lime on a small scale in the summer of 1931. In 1921, three quarries operated here by Irwin Boyer were described by the author as follows:

"The lower beds are best exposed. The stone is hard, grayish blue and weathers to a steel gray. An estimate of the thickness could be made only by measuring the cut along the strike where the stone has been extracted. This cut was 45 feet wide. The gray bed is interleaved with thin, dark beds and the rock breaks with a glassy fracture. Some of these black rocks show slickensided surfaces. The grayer beds contain much calcite vein material. The gray rock, when massive, breaks with a peculiar flat surface which is not unlike a cleavage plane.

"The upper beds, along the western end of the quarry, have been greatly shattered along the axis of the anticline, showing a somewhat pitted surface. There are numerous calcite veins paralleling the bedding planes. The quarry face is about 35 feet high. The upper beds are quite shaly and badly weathered and show much clay in seams. The face is a long continuous one including the second quarry which is a few rods to the west, and which has been abandoned. The gray rock here is not exposed and hence could not be measured.

"The main quarry rock of the Boyer operation is a thin, bluish-black limestone which contains numerous fossils. Here, the whole anticline is exposed and the northern beds have a steep dip, while the dip to the south is only slightly perceptible. Shaly beds and many calcite veins are in evidence along the northern flank. The quarry is being driven along the axis of the anticline. By virtue of the shaly character of the beds, but little blasting is required to dislodge the stone. The cars are run down a gravity plane to the kiln."

Another of the Boyer quarries here encountered several large caves, one of which was said to be 500 feet long.

Between Fremont and Kantz there has been little activity in recent years. In 1888, however, a number of quarries were open there as described in Report F3 of the Second Geological Survey of Pennsylvania (2, pp. 201-204). These descriptions are here quoted.

"Edward Bassler's quarry is opened in the flank of the Firestone ridge just south of Miller's mill, a short distance west of Kantz, having one active kiln with a capacity of 200 bushels. The quarry is not large and the beds are quite cavernous, one seam about 4 feet thick showing a stalactitic structure and exposed for the length of 50 feet on a 50° S. E. dip. The quarry is about 50 feet long and 20 feet deep and at the opening the measures are dipping steeply northwest and cut by cleavage planes, probably the effect of the anticlinal mentioned south of Freeburg. South of this roll in the quarry there are about 18 feet of thin blue beds streaked with calcite, which are largely quarried, the bottom 10 feet being the best. A bed of splintery soft limestone makes the roof and possibly occupies the position of the "soapstone" layer in the Union County quarries. The lime made sells only for farm use.

"The Rausch quarry is about 100 yards further west and has been idle for several years. The same cleavage shows in the first beds met with at the opening; but above them and to the south, there are about 20 feet of the same beds developed in Bassler's quarry. Above these the measures are shaly and the 'creep' of the hill above has curved them into irregular beds, worthless for quarrying. It was no doubt due to the heavy covering of soil which led the proprietors to work their quarry at one time by drifts, one of which extended southward and the other eastward, so as to avoid the crest of the hill.

The operation could not have been very economical, and no quarry in this section of the range displayed such a quality of stone as to warrant such methods.

"Joseph Deal's quarry is about ¼ of a mile west, and when visited in August, 1888, was just being cleaned out after a long idleness, under a lease to James Haines, who proposed to burn lime for farm use. The quarry is about 100 feet long and the dip of the beds is very regular and not over 20-25° towards the southeast.

"The same blue beds of the eastern quarries are exposed here at the bottom of the quarry, over which lie 25 feet of thin shaly stone containing an occasional good bed. Only the bottom stone is burned.

"A second larger and more extensively worked quarry is opened on this same Diehl property, a little to the southeast and on the east side of the ridge, where a small stream has cut down through the Oriskany sandstone chert, making a wide cove in the underlying limestone. The quarry was quite abandoned and its kiln dismantled; but some excellent stone overlying that developed on the north side of the ridge has evidently been taken from the large opening, 125 feet long and 35 feet deep, on a dip varying between 30° to 60°. A total thickness of about 30 feet of stone shows at this point, generally blue, but in rather thin beds near the top of No. VI (Helderberg).

"Sprigman's quarry, on the north side of the ridge, is ½ a mile west of Diehl's and a short distance from Freeburg. It is a small opening, but active, and shoots its stone down from an upper ledge of good blue limestone, which should occur geologically in the interval of rock between the two Diehl quarries.

"The Freeburg quarries in the point of the ridge north of the local anticlinal are operated by four different parties as follows: 1. Hilbish & Miller, one kiln. 2. Bassler & Glass, one draw kiln. 3. Miller & Bickel, one kiln. 4. Batdorff; the latter near the road, being very small and not active.

"There is some good limestone exposed in all these quarries although the total section is small.

"Hilbish & Miller's quarry is a side cut about 50 feet along the face of the ridge and exposes 20 feet of stone in which there are two good blue beds near the bottom, each about 6 feet thick and above from 8-10 feet of shaly limestone. Coal is worth $3 a ton here, one dollar of which represents haulage from Selinsgrove, while lime sells for 7 cents a bushel.

"Bassler & Glass's quarry lies immediately west and is quite similar in its appearance, exhibiting about 30 feet of a rock-section and slightly deeper. Both quarries have about an acre of ground apiece, and both are susceptible of improvement upon greater development.

"Miller & Bickel's quarry is next west and idle. Comparatively little good stone was seen in this quarry, where there was some showing of gypsum mixed indiscriminately through the opening.

"All of these quarries are opened in only medium stone, the best part of the lower beds of No. VI (Helderberg) being still under cover.

"On the road leading south from Freeburg over the ridge to Firestone Valley, the junction of No. VI (Helderberg) and No. VII (Oriskany) is seen on the crest of the ridge in a limestone dip of 35° S. E. Lower down the ridge, but still south of the small subordinate anti-

clinal axis, there are two small limestone quarries, the most westerly being

"Daniel Boyer's, where two kilns were formerly supplied with stone from a quarry 60 feet long and 15 feet deep. Very little good stone shows here, the larger part of the development being in the transition measures between the upper Salina and Lower Helderberg.

"This whole ridge from Middle Creek to Freeburg is sparingly developed, and the best stone can only be reached in a few of the wind-gaps, or at the extreme eastern end of the ridge, unless the overlying Oriskany chert and Stormville shale is first stripped off. The rather gentle dip soon carries any good beds outcropping on the north flank quickly under cover.

"G. C. Moyer has the first quarry in this ridge west of Freeburg, located just at the bend of the road leading over the ridge from S. G. Hilbish's farm. It has been idle for years and was only developed to a limited extent, showing a cut about 50 feet long in which 35-40 feet of limestone is exposed on a dip of S. 50° E. 70°. This steep dip and the covering to be removed in working, probably led to its abandonment. The opening is in the bottom members of No. VI (Helderberg) and the stone is thin-bedding and shows some cleavage.

"S. Hilbish's quarry is perhaps three-quarters of a mile further west along the ridge, about 100 yards south from the road and worked only for local farm use. It shows some fair stone in thin beds near the bottom of No. VI (Helderberg) on a 65° S. dip.

"John Hepner's old quarry is situated at the base of the hill west of the road leading over the ridge and about 2 miles from Freeburg. It was originally opened in the upper Salina lime shales and finally passed through these by a narrow cut into the bottom members of No. VI (Helderberg) which show shaly even yet and rather impure. The dip is about 30°, S. 10° E. and the stone lean and poor."

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SOMERSET COUNTY

With the exception of a band of Catskill sandstone and Chemung shales outcropping in Savage Mountain, all of the surface rocks of Somerset County belong to the Carboniferous Period. Limestone lenses are numerous throughout, although, in the main, they are everywhere of little more than local importance as they cannot compete with thicker and purer limestones quarried in other regions. Nevertheless, they have been utilized for agricultural lime by the farmers of the county.

The limestones of Somerset County are present at several different horizons and at an early date were opened in scores, perhaps even hundreds, of places to supply small quantities of stone to be burned for agricultural lime for local use. In recent years very little limestone quarrying has been done. The crushed stone and lime used in the county, in the main, have been brought in from Bedford and Centre counties.

Little detailed stratigraphic geologic work has been done in Somerset County during the past 50 years and there are a number of unsolved problems. It may well be that some of the limestones described in the following pages are incorrectly correlated. The following geologic section is based upon recent work by G. B. Richardson and J. D. Sisler.

Tentative generalized geologic section of Somerset County

	Feet
Pennsylvanian system	
Upper Pennsylvanian series	
Monongahela group	200
Uniontown limestone	
Sewickley coal	
Fishpot (Sewickley) limestone	
Redstone coal	
Redstone limestone	
Pittsburgh coal	
Conemaugh group	850
Little Pittsburgh coal	
Lower Pittsburgh limestone	
Connellsville sandstone	
Franklin coal	
Lonaconing coal	
Bluelick limestone	
Upper Hoffman coal	
Hoffman limestone	
Upper Claysville coal	
Clarksburg limestone	
Morgantown sandstone	
Wellersburg coal	
Wellersburg (Elk-Lick) limestone	
Barton coal	
Barton limestone	
Federal Hill coal	
Lower Grafton sandstone	
Ames (Berlin?) limestone	
Harlem coal	
Ewing (Coleman?) limestone	
Conemaugh group—Continued	
Pittsburgh red beds	
Upper Bakerstown coal	
Albright (Philson?) limestone	
Lower Bakerstown coal	
Buffalo sandstone	
Brush Creek limestone	
Brush Creek coal	
Gallitzin coal	
Mahoning sandstone	
Allegheny group	250
Upper Freeport coal	
Upper Freeport limestone	
Lower Freeport coal	
Upper Kittanning coal	
Johnstown limestone (cement bed)	
Middle Kittanning coal	
Lower Kittanning coal	
Clarion coal	
Brookville coal	
Pottsville series	180
Homewood sandstone	
Mercer group	
Connoquenessing sandstone	
Mississippi system	
Mauch Chunk series	?
Greenbrier (Mountain) limestone	
Loyalhanna (Siliceous) limestone	
Pocono series	?
Devonian system	
Catskill group	
Chemung group	

In the above section the unnamed shales and sandstones constituting the major portion of the exposed strata are omitted.

MISSISSIPPIAN LIMESTONES

Loyalhanna (Siliceous) limestone. The Loyalhanna limestone lies above the top of the Pocono series. It has been seen on Allegheny Mountain but it seems to be entirely lacking in large areas on Negro

Mountain. It is exposed in Laurel Hill along the western edge of the county, and has been used but little except in the gorge of Youghiogheny River. This limestone is easily identified by its siliceous, cross-bedded character. It ranges from a few feet to 20 feet thick. Its thickness increases northward from the southern Pennsylvania line. It is now being quarried for burning in the northeastern part of the county along the National Highway. Recently the State Highway Department has made tests, hoping to find certain portions of it suitable for road metal.

This limestone was quarried and split into paving blocks in the Youghiogheny River gorge below Confluence more than 50 years ago. If search was made, it doubtless could be found all along the eastern flank of Laurel Hill even though it is in most places concealed by the thick covering of hillside talus.

It probably is present all along the upper slope of the Allegheny Front although it has been recognized in only a few places. It is said to have been quarried at one time in Ogle Township, southeast of Ashtola. It was burned and yielded a white lime containing a large amount of quartz in the form of sand grains.

About 2 miles south of the Lincoln Highway near the top of the steep slope above Breastwork Run, Allegheny Township, the Loyalhanna was observed by the writer at a point where it was proposed to open a quarry to supply highway material. It is a fine-grained siliceous limestone or perhaps more specifically a calcareous sandstone occurring in massive beds. It is greenish gray, but, due to the presence of some pyrite, weathers to a rusty brown. It is reported to be 90 feet in thickness but the calcareous portion is certainly less. It grades downward into a non-calcareous sandstone. According to statements made by the owner some samples of stone from the locality were once accepted by the State Highway Department as satisfactory. A large quarry could readily be opened at this point but it would require the building of 2 to 3 miles of road over which to haul the stone to the Lincoln Highway.

Greenbrier (Mountain) limestone. This limestone occurs in two persistent benches, each ranging from 12 to 30 feet thick. The lower bench lies near the upper geological boundary of the Pocono series. The upper bench of the Greenbrier is usually separated from the lower by sandy shale ranging from 25 to 90 feet thick. This interval of sandy shale often contains thin beds of limestone which are highly fossiliferous. The top bench is usually gray and is locally very siliceous. The lower bench is a pure blue limestone which is often split into numerous benches by lenses of red shale.

Both benches of the Greenbrier were formerly quarried on the west slope of Negro Mountain in Elk Lick Township, Somerset County. Mr. Peck is still quarrying this stone near Glade Mountain. The outcrop of this formation is extensive on the west slope of Negro Mountain but the limestone appears to thin very quickly northward. The northeast dip of the Negro Mountain anticline soon causes the limestone to disappear and it is not seen again until Conemaugh River crosses it in Cambria County.

The lower bench of the Greenbrier is being quarried in Maryland near the Pennsylvania State line, just south of Greenville Township,

Somerset County. In this quarry, the exposed limestone measures approximately 20 feet thick. The limestone dips very severely to the southwest on the eastern slope of the Allegheny Mountain anticline. It also appears to thin northward and its outcrop is seldom seen because the entire mountain is covered by many feet of drift. It was quarried prior to 1910 at one place in Greenville Township. Its position can be readily traced by a very fertile belt of farm land.

In 1929, G. A. Mason was mining a part of the Greenbrier on Piney Run about 1½ miles southeast of Salisbury and about three-fourths mile from the Maryland line. Stone is said to have been mined here for over 40 years and some of the drifts are reported to extend into the hill to the distance of about half a mile. The stone is burned for lime in two kilns and is of good quality. There is a good demand for the lime. The limestone is said to be 80 feet in thickness but this statement could not be verified. The two benches with the interbedded shales probably do aggregate this amount. Only 14 feet of stone is mined. It is a hard, bluish-gray to bluish-black stone of excellent quality, containing many small calcite veins. There are within it a few very thin shale partings. Fossils in the limestone are not as numerous as in many of the Greenbrier beds. Over part of the property the beds are almost flat but in places they dip gently.

The mining conditions are favorable as the roof of shaly limestone stands well. Some entries are as much as 60 feet wide although Mr. Mason is using 30 to 32 foot width.

This locality is promising, although the operations have never been carried on for large production. Until recently another similar mine was worked in the same section.

Howard Peck, Fort Hill, has been working a quarry in the Greenbrier limestone for several years. He sells the stone to the farmers to be burned for agricultural lime.

LIMESTONES OF THE ALLEGHENY GROUP

The Vanport or Ferriferous limestone of western Pennsylvania, having its normal position below the Lower Kittanning coal and a few feet above the Clarion, seems to be entirely lacking in Somerset County.

The Upper Kittanning coal is underlain by the Johnstown cement limestone. It is very persistent throughout Somerset County, averaging approximately 4 feet thick, and ranging from 2 to 8 feet. It is the most valuable geological marker in Somerset County. It has not been quarried commercially but has been opened locally for farm use. This limestone is usually gray or blue-gray, compact and brittle. It is locally cross-bedded.

The Johnstown has been worked near Stoystown where it is 7 feet thick. Although impure, it has been burned for agricultural lime. Three-fourths mile west of Scalp Level, it consists of two layers, the upper of fair quality but the lower one high in iron. It is 6 feet thick where it has been quarried for burning about 3½ miles southeast of Somerset. It has been worked near Jenner Cross Roads and rather extensively along Quemahoning Creek near Sipesville.

Analyses of Johnstown limestone of Somerset County

	1	2	3	4	5	6
$CaCO_3$	63.969	86.778	88.139	79.478	52.940	90.544
$MgCO_3$	4.244	2.908	1.854	10.222	16.060	2.134
$FeCO_3$	4.393	2.972	1.798	3.693	5.800	1.503
Al_2O_3			.340		4.440	.261
S	.385	.166	.357	.168	.068	.464
P	.142	.137	.023	.034	.058	.013
Insoluble residue	24.780	6.040	5.640	4.970	17.770	3.850

	7	8	9	10
$CaCO_3$	50.160	92.298	54.321	69.264
$MgCO_3$	18.494	1.483	23.088	13.773
$FeCO_3$	11.600	1.167	8.492	4.739
Al_2O_3		.359	1.626	.403
$MnCO_3$	---------	trace	trace	trace
S	.153	.097	.127	.106
P	.120	.018	.051	.047
Carbonaceous matter	---------	.550	.980	.590
Insoluble residue	13.360	3.950	12.020	10.760

1. Zimmerman's quarry, three and half miles southeast of Somerset. HHH, p. 155. Compact, sandy; bluish grey.
2. Reitz's quarry, one and a quarter miles south southeast of Friedensburg. Hard, compact; bluish grey.
3. Wilt's quarry, near Stoystown, HHH, p. 128. Compact, fine grained; bluish grey.
4. J. J. Pile's quarry, near Sipesville, on Quemahoning Creek. HHH, p. 232. Compact, brittle; bluish grey.
5. D. Rogers quarry, on Huskin's Run, Shade Township. HHH, p. 146. Hard, rather sandy, bluish grey.
6. Trevorrow's quarry, near Davidsville. Very brittle; fine-grained; bluish grey, with conchoidal fracture.
7. J. Weaver's quarry, about three quarters of a mile west of Scalp Level. HHH, p. 134. Compact, bluish grey; much coated with iron oxide.
8. J. W. Beam's quarry, at Jenner Cross Roads. Upper bench of quarry. Report HHH, p. 231. Compact, brittle; fine grained, bluish grey.
9. J. W. Beam's quarry, middle bench of quarry. Hard, brittle; bluish grey.
10. J. W. Beam's quarry, lower bench of quarry. Compact, brittle; bluish grey.

These analyses are from 8, pp. 295–296.

The Lower Freeport coal is locally underlain by a thin clayey limestone which is of no commercial importance whatsoever. The Upper Freeport coal, at the top of the Allegheny group, is invariably underlain by a bed of good limestone ranging from 2 to 7 feet thick. It is known as the Upper Freeport limestone. Although it has not been quarried for commercial purposes, farmers have opened it at numerous points along the western slope of Allegheny Mountain and southeast of Somerset in the vicinity of Coleman School on the old plank road from Somerset to Berlin. In the northern part of Somerset County, the Upper Freeport limestone is seen wherever the coal above it is mined. Its thickness seems to be irregular in this part of the county and its quality is variable. Locally it is very siliceous and is discolored by pyrite. Its most extensive outcrop is on the eastern flank of Laurel Hill and on the west flank of Allegheny Mountain.

LIMESTONES OF THE CONEMAUGH GROUP

This group contains numerous thin limestones, only two of which may be of commercial importance in the future. It is not improbable that some of the limestones described here may be misnamed. The lower one of the two most promising limestones lying approximately in the center of the Conemaugh group, has been known in certain localities as the Elk Lick. In the publications of the Pennsylvania

Geological Survey, Fourth Series, this limestone is called the Wellersburg after the nomenclature adopted by Dr. C. K. Swartz of the Maryland Geological Survey. Its type locality is Wellersburg, Pennsylvania. This limestone ranges from 3 to 11 feet thick. The top of the limestone is generally very pure, but the bottom part is usually very clayey. At one locality in Somerset County it is mined together with the coal above it. At this locality, on the eastern slope of Negro Mountain just west of Elk Lick, its outcrop is extremely promising. This bed of limestone has been found in practically every drill hole that has been put down in Somerset County.

A thicker limestone, the Clarksburg, occurs in two benches separated by approximately 20 feet of coal, shale, and sandstone. The top bench lies about 225 feet below the Pittsburgh coal and is the purer of the two. This limestone is present only in the Berlin-Salisbury basin of Somerset County. It occurs midway up the hill slopes in this basin and hundreds of tons have been quarried for local burning. Some lenses of this limestone are very pure, others are shaly and siliceous. Much of the lower bench is nodular, the nodules being cemented together by a soft calcareous clay. The nodules are very pure and are picked up on the slopes below the outcrops from which they have weathered and are piled together and burned.

The limestones of the Conemaugh group have been worked rather extensively in the Berlin-Salisbury basin* from Berlin to the Maryland State line. In the vicinity of Berlin and Pine Hill there are four different limestone horizons, the upper three of which have been worked at different times. The last operation was in 1926. The reason for closing the quarries was because of the competition with material shipped in from nearby counties. The stone has been burned for agricultural lime, pulverized and sold for fertilizing purposes, and quarried and sold to farmers who burned the stone on their own farms. The uppermost bed of limestone is supposed to be the (Wellersburg) Elk Lick. It is a bluish gray stone, of fair grade, and has yielded a white lime. It has been variously reported as from 4 to 10 feet thick. From 75 to 90 feet below the Elk Lick there is another limestone known as the Berlin limestone that has been reported by some as 2 to 4 feet in thickness but by others as 8 to 10 feet. It was not seen as the outcrops are so generally concealed by hillside wash. In the case of the lower figures probably only the best portions are included. This rock has been quarried in many places about Berlin. It is a compact bluish limestone and has yielded a good grade of lime.

The third limestone, which has been called the Coleman, lies about 135 feet below the Berlin. It is from 3 to 5 feet thick, is argillaceous and contains thin interbedded shales. Although impure, it too has been quarried.

The fourth limestone, the Philson, is somewhat more than 3 feet thick. It lies low and does not seem to have been quarried much in the Berlin region.

In the vicinity of Garrett some of the Conemaugh limestones have been quarried in several different places but none was in operation in 1929.

Note: The section around Berlin seems to be unusual and until detailed work is done in this area it is impossible definitely to correlate these beds as given by the Second Survey, with the more recent sections of Richardson and Sisler in other parts of the county.

A limestone, supposed to be the Wellersburg, occurs in the vicinity of Meyersdale, one mile west of Meyersdale, and on Tub Mill Creek. Near Salisbury there have been a number of limestone workings. A short distance southwest of West Salisbury is the plant of the Keystone Lime and Coal Co.

Section in quarry of Keystone Lime and Coal Co., West Salisbury

	Ft.	In.
Coal	3 to 3½	0
Shale	2	0
Impure limestone	2	2
Shale		12 to 14
Irregular, somewhat shaly limestone	3	2
Shale		2
Massive limestone	5	0
Shale parting		
Limestone, exposed	11	0

This limestone is probably the Clarksburg, but may be the Pittsburgh. The stone is either burned for lime or pulverized raw and sold to the farmers. There are 4 upright kilns.

The Conemaugh limestones have also been quarried in a number of places in the Confluence or Johnstown Basin and in the Somerset Basin. A limestone quarried one mile south of Forwardstown has been referred to the Berlin. In Middle Creek Township the Conemaugh limestones have been quarried at a number of places. Near Ursina the Wellersburg limestone is divided into two layers. The lower one, 10 feet thick and quite pure, was once quarried on the hillside and the stone let down by an incline and burned in the edge of Ursina. The same limestone was quarried near Draketown.

Berkey Bros., Boswell P. O., were operating a limestone mine just northwest of Glessner in 1929.

Section at mine of Berkey Bros., Glessner

	Ft.	In.
Sandy shale		
Shale		3
Coal		9 to 12
Limestone (mined)	5	6
Limestone (left in mine)	6	
Fire clay		

The stone is massive, breaks in irregular pieces, and is of fair quality. It is probably the Lower Pittsburgh limestone. Some layers contain ostracod fossils. The rooms are driven about 20 feet wide, and the shale above the coal forms a good roof. The coal is used but there is not enough of it for burning the limestone so more must be purchased. Two kilns are used and the lime is sold for agricultural purposes. Production ceases in the winter. The mine now worked is known as the Trexel mine. The same company previously worked another mine in the same vicinity.

William Edmiston has been mining coal and limestone from the same opening near Acosta during recent years. The plant was idle when visited and no information could be obtained. It appears that

very little limestone is taken out. What is mined is burned for agricultural lime.

The Royal Quemahoning Coal Co. operated a coal and limestone mine on the left bank of Stony Creek, 1¼ miles southeast of Stoystown until 1927. The stone was crushed and sold for concrete work. The limestone is reported to be 5½ to 6 feet thick but this statement could not be verified. Until about 1920 stone mined here was burned for lime. About three-fourths mile east of this mine, close to the Lincoln Highway, a small amount of limestone has been mined and burned. In 1929 plans were being made to reopen the mine to obtain both coal and limestone.

Analyses of Conemaugh limestones, Somerset County

	1	2	3	4	5
$CaCO_3$	64.706	90.803	55.589	89.522	80.588
$MgCO_3$	2.156	2.738	14.224	5.327	8.445
$FeCO_3$	4.274	1.986	6.835	1.812	3.314
Al_2O_3	1.700		2.886	.224	.455
$MnCO_3$	--------	--------	--------	--------	1.400
FeS_2	--------	--------	--------	--------	.371
S	2.431	.084	.185	.245	--------
P	.751	.048	.032	.016	.026
Carbonaceous matter	2.602	--------	--------	--------	--------
Insoluble residue	20.660	3.740	19.800	2.500	4.803

1. Lower Pittsburgh limestone, S. S. Flickinger's limestone quarry, 2½ miles north of Salisbury. 50 feet below Pittsburgh coal bed. Compact; exceedingly brittle; structure somewhat slaty; color, dark bluish grey. Carries considerable coaly matter and a large amount of iron pyrites (3, p. 290).

2. Barton (Elk Lick) limestone, Pittsburgh Coal, Coke & Iron Co.'s quarry, ¾ mile north of Ursina. Exceedingly compact and fine-grained; bluish grey, with conchoidal fracture (3, p. 291).

3. Barton (Elk Lick) limestone, Elias Yoder's quarry, one mile west from Meyersdale. Hard, compact, bluish grey (3, p. 291).

4. Barton (Elk Lick) limestone, Peter G. Berkey's quarry, near Jenner Cross Roads. Compact; bluish grey, with conchoidal fracture (3, p. 291).

5. Ames (Berlin) limestone, 1 mile south of Forwardstown. Compact, minutely crystalline; spotted with iron pyrites; color, bluish-black (2, p. 222).

LIMESTONES OF THE MONONGAHELA GROUP

The Monongahela group contains three limestones, the Redstone, the Fishpot (Sewickley) underlying the Sewickley coal, and the Uniontown limestone underlying the Uniontown coal. The Uniontown coal has been entirely eroded in Somerset County. The Uniontown limestone is present only in the high hilltops of the Berlin-Salisbury basin in the vicinity of Pinehill and south of Meyersdale on the western slope of Casselman River.

The Redstone limestone was once quarried near the Maryland State line south of Salisbury where it is said to be 10 feet thick. The Fishpot (Sewickley) has been quarried one mile west of Meyersdale where it is 5 feet thick and consists of two layers, the upper of which is fossiliferous. It was also quarried one mile north of Salisbury where it is 6 to 8 feet thick. A limestone 8 to 12 feet thick including some interbedded clay, which was once quarried three-fourths mile west of Meyersdale and 2 miles southwest of Meyersdale has been referred to the Uniontown limestone. It contains numerous fossils.

Analyses of Monongahela limestones, Somerset County

	1	2	3	4	5
$CaCO_3$	72.623	85.732	74.803	69.160	86.625
$MgCO_3$	12.614	5.098	6.734	15.535	6.152
F_2CO_3	2.239		5.282	3.935	
Al_2O_3	.972	2.871	1.548	1.366	1.825
S	.159	.104	.052	.046	.093
P	.005	.037	.070	.017	.023
Insoluble residue	9.180	6.220	11.510	9.730	4.040

1. Uniontown limestone, Keystone Coal and Manufacturing Co.'s quarry, 2½ miles southwest of Meyersdale. Hard, compact, bluish grey.
2. Uniontown limestone, Saylor Hill quarry, ¾ mile west from Meyersdale. Compact, fine grained, brittle, bluish grey.
3. Fishpot (Sewickley) limestone, J. M. Hayes' quarry, 1 mile north of Salisbury. Hard, brittle; bluish grey.
4. Fishpot (Sewickley) limestone, Saylor Hill quarry, ¾ mile west from Meyersdale. Compact, brittle; yellowish grey.
5. Redstone limestone, Manasses J. Beechy's quarry, 2½ miles southwest of Salisbury. Minutely crystalline; pearl grey, with conchoidal fracture.

These analyses are quoted from 3, pp. 286-289.

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SULLIVAN COUNTY

There are no limestones of importance in Sullivan County. The strata exposed, consisting almost exclusively of sandstones and shales, belong to the Chemung, Catskill, Pocono, Mauch Chunk, and Coal Measures groups. Among the Catskill and Pocono strata, there are some calcareous beds that have been used to a small extent but cannot be said to be of any economic significance now. Platt has published the following statements in his report on the geology of the county (1, pp. 221-222).

Catskill limestones. "Millview is up the Loyalsock from Forksville, and two miles north-northeast of it.

"About half a mile north of Millview, on Mill Creek, Mr. William Lucke has opened a quarry in the lowest of three widely separated exposed outcrops of limestone strata, dipping 7° more or less, southward.

"1. Limestone at Mr. Lucke's house, 200 feet above the quarry rock.
"2. Limestone at the kiln, fully 85 feet above the quarry rock.
"3. Limestone in the quarry.

"Without a more perfect section it would not be possible to locate precisely the horizon of these limestones; but from the structure it seems certain that the uppermost layer of limestone is at least 500± feet below the red rocks which show in the creek bank at Forksville.

"The north dip comes in about half a mile north of this quarry; making the anticlinal axis pass not far to the north. This is stated by Mr. Lucke.

"The limestone layers of the quarry are thus arranged:

	Ft.	*In.*
Small limestone layer, blue	2	0
Red sandstone	8	0
Limestone	2	6
Slate	2	6
Limestone	3	0
	18	0

"The slate thins down at times in the quarry to less than one foot in thickness.

"Specimens of the upper and lower benches of limestone from the quarry were forwarded to the Laboratory of the Survey, in Harrisburg. They were analysed by Mr. S. S. Hartranft, and yielded thus:

	Upper	*Lower*
Carbonate of lime	80.393	69.000
Carbonate of magnesia	5.653	5.387
Carbonate of manganese	3.116	1.689
Sulphur	.240	.092
Phosphorus	.133	.144
Oxide of iron and alumina	5.196	5.870
Insoluble residue	5.240	17.850
	99.971	100.032

"The upper layer represents a very good limestone. When burned it slacks well and is a valuable lime for agricultural purposes; a matter of considerable consequence in this region, where the soil needs a lime treatment.

"*Galena.* Some small specimens of lead ore are found in the upper layer of limestone at the quarry; only in very small pieces, not in any regular deposit; and occasionally there are thin layers of limestones crowded with fossils."

Pocono limestones. South and east of Bernice, Platt (1, pp. 187-188) describes some Pocono calcareous strata as follows:

"On the hillside, south of Schreyfogel's hotel, and 170 feet above the level of the Loyalsock Creek, was opened a quarry of greenish siliceous limestone, poor and sandy, and not fit to burn for lime. The bed is seemingly thin; and it must lie three hundred feet, more or less, beneath the Pottsville Conglomerate.

"A greenish sandy limestone, perhaps the same, is found on the hillside on the south side of Birch Creek, *5 miles east of Schreyfogel's,* near Hopkin's house. It lies fifty feet above the red rocks which come in and extend down to the creek at that place."

Along Fishing Creek, in the southeastern corner of the county, Platt (1, p. 204) also describes some calcareous materials:

"About 600 feet ± below the base of the massive sandstone in X (Pocono), is a massive limestone, fully 12 feet thick. It is chiefly a sandy calcareous rock; but layers of it are made up of rounded pebbles of carbonate iron ore, held together by a matrix of calcareous matter.

"The limestone when burned slacks very well.

"It could not be determined from the weathered outcrop whether the rounded iron ore pieces came water-worn from some other locality or were concretions formed in place."

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SUSQUEHANNA COUNTY

Limestones are of little importance in Susquehanna County although some calcareous strata have in the past received some attention. The surface rocks over almost the entire county belong to the Catskill group. The Chemung strata are exposed in the larger stream valleys in the northern and northwestern portions of the county and in the extreme southeastern corner, the Pocono, Mauch Chunk and Pottsville are present. As in other sections, the Chemung and Catskill contain some calcareous beds, locally termed limestones, although scarcely deserving the name.

Chemung limestones. In the vicinity of Great Bend a calcareous layer within the Chemung outcrops in the valley of Susquehanna River and has been called the Great Bend limestone. It is a thin discontinuous layer ranging from 6 inches to 2 feet in thickness where observed. It is little more than a shale in which there is an abundance of calcareous fossil shells.

Catskill limestones. Throughout the Catskill occasional layers of calcareous breccias are observable here and there. White (1, p. 62) described them as follows.

"The calcareous breccias which everywhere accompany the Catskill rocks in this district, frequently contain pebbles of sandstone, and sometimes of quartz. The pieces of slate are nearly always of a dark olive hue, and present much the appearance of a "slickensided" surface. They also frequently contain what seem to be fragments of fish bones, so broken and worn as to be indeterminable. The calcareous matter often presents a fragmentary appearance, as though it had been formed by the erosion and breaking up of an older limestone."

In addition there is a more persistent calcareous band in the eastern tier of townships that has been called the Cherry Ridge limestone. It is from 5 to 10 feet thick. It consists of fragmental fish bones, sand, shale pebbles, etc., cemented by calcium carbonate. Some Wayne County specimens analyzed have shown as much as 65 per cent $CaCO_3$ although most contain less than 20 per cent. Some fishbed conglomerates similar to those described by White in Wayne County are exposed along the D. L. & W. Railroad south of New Milford. They are evidently extremely low in $CaCO_3$.

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TIOGA COUNTY

The strata of Tioga County belong to the Chemung, Catskill, Pocono, Mauch Chunk and Coal Measures groups. All of these consist almost entirely of shales and sandstones. However, interbedded with these argillaceous and siliceous sediments there are occasional impure calcareous strata consisting of great masses of fossil shells. These are more prominent in the Chemung although occasionally noted in some of the other groups.

So far as known no use has been made of these calcareous beds within recent years. When transportation facilities were inadequate some local use was made of these strata, impure as they were, for agricultural lime and for furnace flux. The writer's limited investigations lead him to believe that there are no limestones of economic importance in the county.

The following quotations from Sherwood and Platt's Report on Tioga County show the characteristics of these limestones or calcareous shales and sandstones.

On the farm of G. R. Wilson "in the south bank of Mann's Creek" near Mansfield "there is a bed of limestone or calcareous rock, said to be six feet in thickness, which has been worked quite extensively to supply a flux for the iron furnace at Mansfield, for which purpose it seems well adapted. It has also been burned for lime.

"It is largely composed of comminuted sea shells, which must have been ground up and broken to fragments by the action of the waves. The dip is northerly. Is this bed the same as that worked by W. B. Kline at Burlington, in Bradford County. Is it the same as that referred to as occurring two miles north of Mansfield, by Richard Cowling Taylor, in his memoir on the Blossburg Coal Fields? Its properties will be seen by the following analysis by David McCreath: Fe_2O_3 2.142, Al_2O_3 2.269, CaO 28.872, MgO 1.117, H_2SO_4 .087, H_3PO_4 .729, CO_2 23.227, Insoluble residue 41.700, Total 100.143."

"At Knoxville (1. p. 94) the limestone must underlie the surface at no great distance; as it was opened on the Cowanesque Creek, two miles below Knoxville, showing two feet of poor, fossiliferous limestone."

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UNION COUNTY

Limestones are fairly well distributed throughout Union County as they are present in every township of the county with the exception of Hartley. However, three of the largest townships—White Deer, West Buffalo, and Lewis—contain very little limestone. The other six townships are well supplied.

The limestones of Union County have been quarried in scores of places to obtain small quantities for burning. As in other counties in central Pennsylvania, most of these openings have long been abandoned although lime is still being produced in several places. In recent years the demand for crushed stone for highways and for concrete construction has resulted in the reopening of some of these old workings and new quarries have been started in places favorably situated. Near Winfield there has long been extensive quarrying, first for the manufacture of lime, but at present to obtain crushed stone for some of the new State roads of that section.

The limestones of Union County belong almost entirely to the Helderberg group, although some calcareous beds referred by the Second Geological Survey of Pennsylvania to the Salina are present and have been utilized in a small way.

HELDERBERG LIMESTONES

The Helderberg limestones occur in four bands in Union County. The most northerly band cuts across Gregg Township from Lycoming County into Northumberland County, passing through Alvira and in a direction slightly south of east crosses Susquehanna River about three-fourth mile north of Allenwood.

The second band forms a loop open on the east and closed on the west, which encloses the town of Lewisburg. It enters from Northumberland County about 1½ miles north of Lewisburg, goes westward about 5 miles to the vicinity of Cameron and Buffalo Cross Roads, where it turns eastward and crosses the river into Northumberland just south of Lewisburg.

The third band forms a ridge known as Mifflinburg or Limestone Ridge, which extends from near Swengel in Hartley Township eastward, passing just south of Mifflinburg, a short distance into East Buffalo Township. It forms the trough of a synclinal valley so that the Helderberg limestones outcrop in two bands in close proximity. A small isolated patch of the same limestones with similar structure is also present about 2 miles south of Mifflinburg.

The fourth band crosses the county in a direction slightly south of west, through the central part of Union and the extreme southern part of Limestone Township. It enters the county a short distance south of Winfield, passes through New Berlin and crosses into Snyder County about a mile south of Battletown.

DESCRIPTION BY DISTRICTS

Gregg Township Area. The most northerly band of Helderberg limestone has been worked for a long time south of Alvira, a short distance north of Spring Creek. Quarries there were described in 1888 by d'Invilliers as follows (2, p. 86).

"Leonard G. Meek's limestone quarry is opened in the Lower Helderberg formation along the center of the little synclinal basin and just north of Spring Creek; and H. Scott has opened the same rock series at the east end of the same ridge on a small branch of the main creek.

"The limestone quarried at both places is not over 40 feet thick and occurs in rather thin beds, somewhat stained with red clay seams. The entire 40 feet of limestone is burned for building and plastering lime, as well as for farm fertilizing; and in each quarry there is a bottom gray limestone and some blue beds on top which would further amplify the section by about 20 feet.

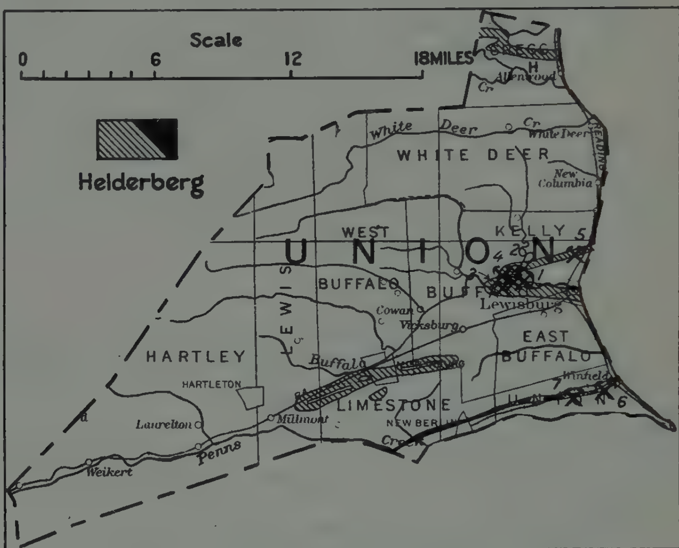

Fig. 33. Limestone areas in Union County.

1. John H. Voris. 2. Penn-Lohr Lime Co. 3. Buffalo Township quarry. 4. Charles Yost. 5. M. A. Grove. 6. Smith Bros. 7. Charles Reichley.

"During the active season Mr. Meek stated that he burns 20,000 bushels in two kilns, 20 feet high and 6 feet wide at top, using a ton of anthracite pea coal to each 100 bushels of stone burned. The limestone beds seem to lie perfectly flat at his quarry, showing a slight tendency to turn up at the north and south sides.

"The Lower Helderberg limestone folds over a small anticlinal axis near the Presbyterian Church, and passes thence along the public road westward to Alvira, on north dips of about 12°, and eastward passes through the forks of the road near the Baptist Church and thence to the Susquehanna River.

"Bowers' quarry is a small opening in the limestone a short distance west of the railroad, where the beds seem to be considerably twisted, some of them showing dips of about 50° towards the southeast. The quarry was idle and the stone exposed rather inferior."

In recent years, Galloway and Meek have worked here.

A thin, shaly limestone forms the north-northeast wall of the quarry, and a fairly good lime is obtained from it. There are numerous red-

dish clay seams in the overburden and also in the overlying grayish limestone, which reaches a thickness of 40 feet. This gray limestone is underlain by a more bluish limestone about 20 feet thick which breaks with a distinct glassy fracture.

Lewisburg Area. The most active limestone quarrying in the Lewisburg region is on the southeast, south, and west slopes of the hill about 3 miles west of Lewisburg, which is practically bounded on the west, north, and east by Buffalo Creek. In the summer of 1931, John H. Voris was operating a small quarry, opened in March, 1931, in the southeast part of the hill. In the main opening, the beds worked are gnarly, tough, dark limestones. The deepest part of the quarry was only about 18 feet. Many bad clay pockets extending to the bottom of the opening presented a serious obstacle. Another opening nearby exposed only thin-bedded limestones containing many *ostracod* and small *gastropod* fossils. The entire output is crushed stone. The quarry was only in the first stages of development when visited and will doubtless present a more favorable appearance later.

The Penn-Lohr Lime Co. is working in an old quarry on the south side of the hill. The quarry face extending along the slope of the hill is about 55 feet high and the strata dip into the hill at an angle of about 40°. Much of the stone exposed in the quarry is of poor quality, shaly and siliceous, but there are several layers of good stone. A 7-foot bed near the base is said to have formerly been worked for fluxing stone used in blast furnaces in Milton. All of the stone now being quarried is burned for lime. There are two kilns on the property.

A short distance to the west is a quarry worked intermittently by Buffalo Township for crushed stone for the township roads.

On the west side of the hill, Charles Yost was working a quarry and burning lime in two kilns. This quarry was not visited.

In 1888 there were more quarries in operation and better opportunities to see the different strata than at present. For that reason the following paragraphs are quoted from Report F3 of the Second Geological Survey of Pennsylvania (2, pp. 102-104).

"In Buffalo Township are several openings in the Lower Helderberg limestone, occurring in the south flank of the limestone ridge west of Lewisburg.

"These in order westward are the quarries of Messrs. Gepheart (erroneously printed Gephew on map); Cameron, or Duck; Wolfe; Wolfe No. 2; and on the western point of the ridge along Buffalo Creek, Beaver's or Miller's quarry. None of these openings were very actively worked in the summer of 1888, and it was with difficulty that any information could be obtained concerning the markets or the general commercial characteristics of the stone; but they are evidently mainly worked for local farm use and plaster lime.

"J. Wolfe's No. 1 quarry, on the south side of the hill, is about 250 yards north of the pike and near the crest of the ridge. It has been mainly worked to produce farm lime, which is burned in two kilns. The dip is gentle, not over 20°N. 5°W., and upon this dip the quarry exposure, which is about 50 feet square, shows about 60 feet of rock, capped with shaly fossiliferous beds, not worked. There is one good massive blue bed in the north face of the quarry, from 12-15 feet thick, separated by about 15 feet of small one foot beds from

a lower deep blue bed of excellent quality, about 6 feet thick, smooth grained and very free from siliceous matter. These two beds are chiefly worked here; the underlying beds exposed are all shaly and not burned.

"Martin Wolf's quarry is about 1/4 of a mile east and differs in no essential points from the one just described, except for a slightly steeper dip.

"The Cameron quarry (now Packer) is about 1/4 of a mile east and was being actively worked during the summer of 1888. All kinds of lime are made here upon demand, and the average output is from 6 to 7 thousand bushels of burned lime per month.

"The quarry is opened geologically and topographically like the others in this hill, and exposes a rock section, 50 feet more or less thick, dipping 25°NW. The upper 25 feet is shaly and white, and is rarely used. Beneath this there is a good 10 foot blue bed separated by about 6 feet of shaly beds from a lower 6 foot blue bed, corresponding to the two main beds of the other quarries and apparently associated with the Bossardville horizon described in G7, embracing the counties on the east side of the Susquehanna River.

"The quarry is about 150 feet long, but narrow, and most of the information regarding markets and use of lime was withheld.

"Gepheart's quarry is next east, separated by a small quarry formerly worked by Cameron. But these latter openings were idle and both small.

"The Beaver, or Miller, quarry is situated high in the ridge about 1/4 of a mile down Buffalo Creek from Hafer's grist mill in the north leg of the synclinal on a low E.S.E. dip. Probably 60 feet of good blue stone is exposed here 200 feet above creek level, and in the interval there are several additional ledges of limestone rather more white and gray, so that the entire series cannot be less than 200 feet in thickness, estimating the top layers of the upper Salina beds to be above creek level here.

"The quarry was being operated by Mr. Stall, but was not active at the time of inspection.

"The limestone can be quarried here with great advantage and cheapness, as the opening is practically in the center of the synclinal and can be worked in both directions with equal advantage."

About 3 miles north of Lewisburg and 1 1/4 miles south of West Milton, M. A. Grove has been quarrying Helderberg limestone and burning lime intermittently for a number of years. The quarry is located between the highway and the Reading Railroad which here closely follows the Susquehanna River. The available quarrying area is therefore limited. The ledges exposed dip south about 18°. Some beds are fairly massive and consist of dark gray stone of high quality and breaking with a distinct glassy fracture. These are interbedded with gnarly strata of poorer quality containing frequent shale laminae. Clay pockets filling old solution cavities extend down to depths of 10 to 20 feet. Although there are a number of objectionable features in the quarry, stone suitable for agricultural lime can be obtained. There are four kilns on the property, of which two were in use when the plant was visited in the summer of 1931. At one time some raw limestone was pulverized here by the Shikelimo Lime Co. It was

sold under the analysis of 95.57 per cent $CaCO_3$ and 2.10 per cent $MgCO_3$. Some stone of that grade can doubtless be obtained by careful selection but the run of quarry is much lower in its lime content.

Mifflinburg Ridge Area. The third band of Helderberg limestones forming the Mifflinburg Ridge area has been long worked. The following paragraphs from the first edition of this report describe the operations in 1921.

"At Swengel, there are numerous small operations, all on the north side of the ridge. At this point it would be well to mention the fact that the economic value of the burned lime in this section is greatly lessened by the 'cut-throat' methods of the various small operators. Lime was sold at 9 cents a bushel during the summer of 1921, while in other areas where larger operators were at work, lime ranged from 17 to 28 cents a bushel.

"At the quarries the men constantly refer to the so-called 'bastard' limestone, a name which was used frequently in the literature during the time of White, Platt, d'Invilliers, and others. The rock is a more siliceous limestone. Here the so-called 'bastard' limestone overlies the good black limestone which could be easily quarried by benching into the hill in the lower portion.

"The operators from east to west are:—Knauss Brothers, C. R. Ruhl, (2 quarries), J. C. Coleman, C. R. Ruhl, Charles Dorman, C. R. Ruhl, D. H. Catherman, and the township quarry. The quarries working at the time of the visit (1921) included the Knauss, Dorman, and township operations. The outcrop can be traced for a quarter of a mile along the hillside. The quarries have been in operation for the past 25 years. The total output is about 2500 bushels a week.

"The basement rock of the Swengel quarries is a black limestone with some calcite veins. The thickness could not be estimated because of the overburden. The lowest bed being worked is about 4 feet thick. It is quite siliceous and is overlain by a thin-bedded, somewhat shaly rock about 10 feet thick. Above this shaly bed, a dark blue limestone occurs which in places is somewhat gray, grading into a shaly limestone. Many caves have been broken into in the course of quarrying.

"The extreme western outcrop where the township quarry is located shows limestone to a thickness of 20 feet. For the most part it is a grayish-blue limestone, weathering buff and showing many poorly preserved fossils on the weathered surfaces.

"In the quarry of the Limestone Products Company, which is on the ridge directly south of the town of Mifflinburg, the same beds as those described in the Swengel area are found. They are better exposed. Here the stone is crushed for road materials, and some of it is burned for lime. At the time of our visit the quarries of the district were furnishing stone for the State road to Bellefonte.

Section exposed in the Limestone Products Co. quarry

	Feet
Keyser limestone:	
Thin bedded, more or less shaly limestone	10
Bluish gray hard limestone	20
Massively bedded limestone	36
Blue to black limestone	12
Shaly limestone	7

"Farther west, but in beds represented by White's Lewistown limestone, are the quarries of J. P. Miller and the abandoned quarry of Emanuel Snyder.

Section exposed in the J. P. Miller quarry.

	Feet
Shaly and thin-bedded limestone	12
Massive blue limestone	10
Hard, siliceous limestone	12
Black limestone (thickness determined by diamond drill)	35

Section exposed in the Emanuel Snyder quarry

	Feet
Shaly limestone in very thin beds	10
Blue limestone, irregular fracture	20
Bluish gray limestone, massive	20
Blue limestone, smooth and good quality	8
Fine-grained limestone, two-foot beds	6
Gray, shaly limestone in base of quarry	10

"The strike of the rocks in this locality is almost due east and the dip 24°S. *Crinoids* and *brachiopods*, poorly preserved, were found in abundance in the Snyder quarry. The Miller quarry shows large joint planes, many clay seams and pockets."

About two miles southwest of Mifflinburg, two small openings are found about half a mile apart. The westernmost quarry was opened years ago for foundation material. The quarry to the east was opened several years ago to supply stone for highway construction.

The stone occurs in a ridge trending about N.60°E. and the beds have approximately the same strike. The dip is about 30°SW.

The following analyses were obtained from samples collected at these quarries:

Analyses of limestone at quarries two miles southwest of Mifflinburg

	1	2	3	4	5	6
$CaCO_3$	94.35	95.36	95.05	95.72	89.72	87.01
$MgCO_3$	1.85	1.83	2.04	1.47	2.06	2.44
Al_2O_3, Fe_2O_3	1.40	2.00	0.84	1.32	4.16	4.44
SiO_2	2.10	0.68	2.02	1.66	4.32	5.72

1. Western quarry. Float sample.
2. Western quarry. Five feet of beds, top of quarry.
3. Western quarry. Three feet of beds, immediately below 5-foot sample.
4. Western quarry. Eight feet of beds, below 3-foot sample.

5 and 6. Eastern quarry. Two samples representing about 35 feet of beds.

The descriptions published in Report F3 of observations in 1888 furnish additional information of value. They are as follows (2, pp. 131-132):

Lewis Township. "In Lewis Township at the western extremity of Mifflinburg ridge there are a series of small quarries opened on the north side of the hill in the Lower Helderberg limestone, extending for about 1000 feet along the outcrop to the end of the ridge, and one opening, Halfpenny's, on the south side.

"They are all small local quarries, generally run from time to time as their product is required for farm use, each farmer owning a strip about 2 rods wide, east and, west, and 50 rods long, north and south.

"J. Ruhl's quarry is the first and most eastern, having one kiln; quarry about 30 feet wide and exposing 15 feet of rock, only slightly developed on a southeastern dip of 10°.

"S. F. & H. W. Ruhl's quarry is about 100 feet further west and shows about the same amount of development. It is 50 feet long, and shows 18 feet of blue limestone in thin beds; one kiln.

"William Fees' is the next small opening, with one kiln. It is worked partly for farm and partly for general trade use, opened on the same section of beds as the last.

"I. Reiss and D. Knauss have a quarry and a pair of kilns next west; and D. Knauss a single kiln, all furnished from one large quarry, showing a section of about 30 feet of stone, the bottom 20 feet of which show good massive blue beds from 6 inches to 2 feet in thickness, pure and making an excellent lime. These beds have not apparently yet been reached in quarries further east and are not far below the summit of the hill.

"William Fees' come next with two kilns, supplied from one quarry about 30 feet wide and 25 feet north and south, where a small portion of the lower and upper beds have been developed sparingly.

"George Ruhl has a small quarry immediately adjoining, but no kiln. It shows about the same features as the last.

"William Fees again joins him on the west with one kiln, practically making a continuous quarry.

"J. Speese has the last quarry on the western extremity of the ridge, with one kiln and about 20 feet of rock, dipping very gently 10-15 towards the south.

"In other words all these quarries are practically upon one series of beds, aggregating about 60 feet in thickness, all the openings making nearly a continuous quarry. All the coal used here is hauled from Swengle Station, one mile, at a cost of about $2.40 at the railroad, and very little attempt is therefore made to manufacture any lime except for local use.

"J. R. Halfpenny's quarry, on the south side of the ridge, develops the same stone on a north dip.

"The Ore sandstone ridge in this township is largely eroded by Penns Creek and when it gets to the south side of that stream the rocks dip so steeply as to form only an indistinct terrace on the north flank of Jack's Mountain.

"The Bloomsburg red shales however show distinctly at the base of the ridge, just south of the valley road, and are crossed going to Rearick's saw-mill on Penns Creek on a low 15°NW. dip, which spreads them over quite a wide area."

Limestone Township. "The Mifflinburg ridge (2, pp. 115-117) in the northern portion of the township, has already been referred to as containing a good series of limestone beds. About a mile west of Mifflinburg there are three small quarries opened about 250 yards south of the pike, all in the same portion of the Lower Helderberg formation, as exposed in the large town quarries on the West Buffalo line. The dip is about S. 15°E. 10-20°.

"Royer's quarry, with two kilns, is the first operation; Kleckner's with one kiln, the second; and Youtz's, with one kiln, the third. The first two are practically continuous, and expose about 30 feet of rock, including the soft blue-gray stone, for a distance of about 100 feet along the outcrop. The Youtz quarry is about 100 yards west, and while it was not thoroughly developed, presented a face of excellent stone. None of these quarries were being operated when visited and are probably only developed for private farm purposes.

"J. Strickler had just started a small quarry along the north flank of the ridge, about one mile west of the Youtz quarry; but comparatively little stone had been quarried here.

"Immediately south of Mifflinburg and somewhat higher in the ridge than the town quarries:

"Anspach & Cotelius' quarry is opened close to the synclinal in limestone, dipping about 5°SE., the reverse dip showing a little higher on the ridge. The stone exposed here is not burned at all and occurs geologically above the good fat-lime beds of the Lewistown formation, and is largely developed for building and paving purposes in Mifflinburg. It has a blue color and is exceedingly hard, breaking out in small or large blocks as required, and apparently an excellent stone for the purpose for which it is required. There is about 20 feet of rock exposed in the quarry, the thickest layer so far developed being about 14 inches. One bed of good limestone, about 2 feet thick makes the bottom rock of the opening.

"The King quarry is located just west of the road leading to White Springs, opened in the massive limestone series of No. VI (Helderberg), and furnishing an excellent quality of lime. It is a small opening however, and has not as yet developed any thickness of rock.

"R. & D. Longs' quarry is situated a couple of hundred yards west on the east side of the next road crossing the ridge, where the limestone developed and burned is of first-class quality. The general trade is supplied from this opening, field and plaster lime selling at 7½ cents per bushel for 'run of quarry,' and 10 cents for picked lime.

"The rock section exposed is about 40 feet thick, the lower 25 feet consisting of good blue beds, less siliceous, and are said to make the best plaster lime, but no better for fertilizing purposes than the upper beds.

"The quarry is about 70 feet long and is equipped with two kilns, one of which is kept going constantly. Work has been carried on for about 2 years, averaging about 9 or 10 thousand bushels per year. The dip is S. E. about 10° and the Oriskany sandstone and chert caps the ridge above the opening where it has been somewhat quarried for road purposes; but it only makes a small knob at this point, bring eroded to the east and west. It is about 15 feet thick.

"From Long's quarry to White Springs the synclinal of the limestone ridge is crossed further west, where it again holds a strip of the Oriskany sandstone measures.

"Barber's quarry, just north of White Springs, has developed the bottom members of No. VI (Helderberg) on the south flank of the ridge, largely exposing a gray and white stone, not particularly good. There should be better layers opened higher in the ridge. The dip is about 15°NW., increasing to about 35° southwards in the upper

Salina lime shale valley, which spreads out between the limestone ridge and the Bloomsburg red shale, east of White Springs.

"Along the eastern end of the Mifflinburg ridge the No. VII Oriskany rocks again cover the crest with a thin mantel of broken sandstone and shale, the ridge being slightly divided here by a narrow valley, but keeping a nearly dead level eastward, where the two prongs come together again.

"Hassenplug's quarry is a large opening on the south flank of the ridge and west of the road to New Berlin, where the dip is about 10°NW. The quarry was idle during 1888 and shows a somewhat similar rock section to the Mifflinburg opening."

West Buffalo Township. "At Mifflinburg (2, pp. 108-110), the pike is close to the northern edge of the Lewistown limestone in the Mifflinburg ridge; but there is a comparatively small area of those rocks exposed in this township, (West Buffalo) the greater part of the ridge lying in Limestone Township, to the south. All the openings immediately south of Mifflinburg were idle in 1888, although only temporarily so, and the extensive quarries south and east of the town all showed good sections of the limestone measures upon 30°SE. dips. The limestone industry, however, has evidently deteriorated for some reason at this point, for many of the kilns have been entirely dismantled as if the owners did not contemplate an early resumption. With railroad facilities so near at this point it seems strange that an extensive operation for quarrying and shipping both stone and burned lime is not inaugurated, for there would seem to be no good reason either in the character of the stone or in its location to prevent such an operation being successful.

"The Benchof, or Tees quarry, is the most eastern opening and is worked periodically. It shows some excellent stone, the lower portion 10 to 20 feet thick, consisting of a good blue and gray rock, fine and smooth-grained; 15 feet of darker rougher stone, but of good quality and from 10 to 20 feet of thin beds on top, the dip is S.10(0)° E.30°.

"A section of this quarry from top to bottom amounts to 66 feet, thus:

		Feet
1.	Shaly limestone, in very thin beds	10
2.	Blue limestone, irregular fracture, and weathering rough	20
3.	Bluish-grayish massive bed, somewhat jointed	12
4.	Blue limestone, smooth grained and of good quality	8
5.	Dark blue limestone in beds 2 feet thick	6
6.	Gray shaly limestone in bottom of quarry	10

The opening is about 100 feet long east and west, and has been a large producer in the past, though idle during the summer of 1888. An excellent quality of lime should be made here.

"Some little development has been made in a smaller quarry immediately east, equipped with two kilns and developing largely the upper strata.

"Mifflinburg borough owns the next quarry further west, where the same rock section practically is exposed on a dip of only 6-10°SE. This is sometimes known as the Wolf quarry.

"The Mench quarry shows a similar dip and is located just west of the road crossing the ridge to Centerville and the

"Faust or Hearn quarry lies a short distance still further west on the south side of the next road crossing the ridge and is close to the Limestone Township road."

Buffalo Township. "In the Mifflinburg ridge (2, p. 104), which is also sometimes called the 'Limestone Ridge' by the local inhabitants, there are one or two small quarries close to the Limestone Township line, opened near the crest, with dips of from 15-20°N.W. This ridge is of synclinal structure, and in its length of 7 miles, contains three narrow compressed strips of the Oriskany sandstone, separated from one another by erosion along the crest of the ridge. The eastern extremity contains limestone throughout and its southern crest has been cut down in a desultory manner for several hundred yards along properties of Messrs. Frock & Bucher.

"Henry Frock's quarry, which is the more eastern, is only worked for private farm use; but the stone is in fair condition to develop well and enable an excellent quarry to be opened at this point.

"The Rev. Mr. Bucher's quarry is really a series of small openings for several hundred yards along the hill, beginning at 1/4 of a mile west from Frock's opening and extending to, if not entirely in, Limestone Township. A very small section of the limestone measures is exposed in any of these openings, although the stone worked is apparently of excellent quality."

The above descriptions furnish evidence of the decline of limestone quarrying in Union County.

Winfield Area. In the southern band of Helderberg limestone, the most extensive quarrying has been carried on about half a mile southwest of Winfield. It is the largest operation in the county and one of the largest visited in the entire study of the Helderberg. The quarry is about a quarter of a mile long and the face reaches a height of 150 feet. The beds pitch steeply to the south at angles of 46-54° and strike N.77°-84°E.

The output when visited in 1921 was 1200 bushels of lime per week and as needs arise the quarry has a total capacity of 750 bushels daily. There is a battery of 15 kilns on the property. When visited in the summer of 1931, the product was entirely crushed stone for highway construction. It was being worked by Smith Brothers.

Section exposed in the Winfield quarry

	Feet
Shaly limestone	6
Thin, massive limestone, beds 10 inches and thicker	27
Massive seamy limestone	8
Massive blue limestone, solid beds	5
Grayish blue limestone, in thin beds	8
White to bluish limestone	6
Shelly limestone	6
Thin beds of blue limestone 3 to 6 inches thick	5
Blue limestone of good quality	3
Thin beds of blue limestone	7
Smooth blue strata with thin slate in center	8
Good blue limestone	10

The so-called "bastard" limestone constitutes the series from the shelly beds upward. The overburden varies from 1 to 6 feet.

At an abandoned quarry 1½ miles west of Winfield the following section was observed.

Section in quarry 1½ miles west of Winfield

	Feet
Blue beds, generally under one foot in thickness	25
"Bastard" shelly limestone	6
So-called "plaster" beds	35

In the summer of 1931, Charles Reichley was operating a quarry and burning lime in two kilns on the south side of the highway about 3 miles west of Winfield. He had been working about a year. He first started to work in an old quarry, but the stone was gnarly, unusually heavily bedded, so that it was very expensive to hand drill and shoot. One bed exposed is almost 15 feet thick. A new quarry has recently been started a short distance to the east where beneath about 12 feet of broken and weathered rock, gray and bluish-black stone of fair quality is being obtained. The bluish-black stone is of very good grade and breaks with a glassy fracture. The gray stone is tougher and less pure. Both quarries are on the north slope of a low hill. The beds dip southward into the hill at an angle of about 40°.

SALINA LIMESTONES

Strata that were referred by the Second Geological Survey of Pennsylvania to the Salina contain some impure limestones in different parts of the county. So far as known, these have not been worked for many years. Therefore the following paragraphs from Report F3 of the Second Geological Survey of Pennsylvania describe observations made in 1888.

"On the road leading west (2, p. 90) about a mile below White Deer Mills, a narrow compressed synclinal of Salina lime shales crosses the road near Rauck's house, and thence west keeps north of the road leading to White Deer church, marked by a series of low hills. Each individual farm has a small limestone quarry opened in these upper Salina rocks, and while the beds are only a few feet in thickness, interbedded with shales, they furnish a fair quality of crystalline blue limestone, rather quartzose, burned for farm fertilizing.

"At Monpeck's quarry the rocks dip nearly due north and south 25° and 40°, but are much curled and twisted and interleaved with thin bands of shale. All these quarries make rather poor exhibits, but in the absence of the thicker and purer Lewistown limestone beds in this township they are naturally largely utilized.

"These limestone and lime-shale rocks occupy the center of this narrow valley for 6 miles west of the Susquehanna River, flanked on each side by the underlying Bloomsburg red shales, the latter rocks forming low but distinct ridges, and giving rise to an intensely deep red soil in strong contrast with the gray soil of the lime-shale valley."

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VENANGO COUNTY

The limestones of Venango County are of little economic importance and in recent years little quarrying has been done. The Vanport is present but its limited occurrence in the southern part of the county prevents it from ever becoming very important.

Generalized section of Venango County

Pennsylvanian system
- Allegheny group
  - Kittanning sandstone and shale
  - *Vanport (Ferriferous) limestone*
  - Scrubgrass coal
  - Clarion coal
  - Fire clay
  - Brookville coal
- Pottsville series
  - Homewood (Piedmont or Tionesta) sandstone
  - Tionesta coal
  - Tionesta iron shales
  - *Upper Mercer (Upper Wurtemburg) limestone*
  - Upper Mercer coal
  - Upper Mercer iron shales
  - *Lower Mercer (Lower Wurtemburg) limestone*
  - Lower Mercer coal
  - Lower Mercer iron shales
  - Upper Connoquenessing sandstone
  - Quakertown coal
  - Quakertown iron shales
  - Lower Connoquenessing sandstone
  - Sharon iron shales
  - Sharon coal
  - Sharon conglomerate

Mississippian system
- Pocono series
  - Burgoon group
  - Shenango shale
  - Shenango sandstone

The above section includes only the named beds but there are in addition many other unnamed shale and sandstone members that are not mentioned.

CARBONIFEROUS LIMESTONES

Lower and Upper Mercer limestones. Little information has been obtained concerning the Lower Mercer and Upper Mercer limestones of Venango County. Search throughout the central and northern portions of the county would undoubtedly reveal their presence. Each of them is about 2 feet in thickness and hence of no value except where a small amount of stone only is desired and the beds outcrop in such a way as to yield the stone without excessive stripping. In all probability they were utilized locally in many places throughout the county 50 to 75 years ago in the period when it was a common custom for the farmers to burn their own lime for agricultural use.

Vanport limestone. The Vanport limestone is developed in patches near the tops of the highest elevations in Irwin, Clinton, Scrubgrass, Richland, Rockland, and Cranberry townships. In the last two there are only a few very small areas where the Vanport still exists. It seems probable that at one time this valuable limestone extended over the greater portion, if not all, of the county but has since then been largely removed by erosion.

The Vanport of Venango County, except being thinner, is similar to that of Butler, Armstrong, and Lawrence counties where it is best developed. It is a high grade limestone suitable for lime, cement, crushed and pulverized stone. It is usually 6 to 10 feet thick.

In 1919, C. R. Fettke studied this limestone to collect information concerning stone that might be readily obtained for highway construction. The notes which follow are taken from his unpublished report.

DESCRIPTION BY DISTRICTS

Irwin Township. Quarry of J. I. Huntsberger west of Barkeyville. Thickness of face, 8.4 feet. The present face 120 feet long can be extended to 1500 feet, and quarried back for 200 feet. Available quantity, 200,000 tons.

Quarry of Boyd Harris, ¾ mile east of Mechanicsville. Thickness of face, 6 feet, with face not fully exposed. An area 1000 feet by 500 feet can be quarried without excessive cover. Available quantity, 250,000 tons. Transportation facilities, one-half mile haul to State highway northeast of Mechanicsville.

In the southeastern part of the township on the northwest side of Pittsburgh and Franklin Highway, a face of limestone 1500 feet long and 6 feet or more thick can be opened under cover not exceeding 18 feet, and will yield 100,000 tons of stone available for that highway. Other outcrops along the highway may be opened for like purpose. Over the township generally the Vanport is thin.

Clinton Township. Quarry of William Witherup one mile north of Anderson Stone House. Thickness of face, 15 feet on an area 1500 feet long and 1000 feet wide, under cover of 10 to 20 feet. About 2,000,000 tons can be quarried. Transportation facilities, haul of 1½ miles to the Emlenton-Clintonville State highway.

On the farms of F. Atkin, the Calvert Heirs, G. N. McFadden, W. N. Riddle and L. Scott, approximately two miles east of Clintonville. Small openings show a face 8 feet thick, and drill holes are said to have passed through 18 feet. This area is under light cover and a large quantity of good stone available on the several properties could be delivered with a comparatively short haul to the Emlenton-Clintonville State highway.

Scrubgrass Township. Quarry one mile east of Crawford Corners and 500 feet south of State Highway. Thickness of face, 9 feet or more. The present face can be developed in length to 1500 feet and quarried back 200 feet. Available quantity, 200,000 tons. Transportation facilities, close to State Highway.

Immediately north of Anderson Stone House a face 3500 feet long with a thickness of 15 feet can be opened and quarried back for a distance of 300 feet, and would yield 1,000,000 tons. Transportation facilities, ½ mile haul over a dirt road to Emlenton-Clintonville State highway.

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WARREN COUNTY

Warren County is not known to contain any limestones that can be used. In a few shale and sandstone strata the fossil shells are so abundant that there is an appreciable content of calcium carbonate, but not sufficient to justify designating them as limestones.

WASHINGTON COUNTY

Washington County is abundantly supplied with limestone; almost every square mile has limestone either outcropping or near the surface. The strata are interbedded with shales to such an extent that in some places the intervals named below as limestones may, in many localities, contain fully as much shale as limestone.

The geologic structure of the county consists of low anticlines and synclines so that rarely do the strata dip more than a few degrees. The region is deeply trenched in all portions with steep-sided stream valleys, thus furnishing numerous outcrops.

Generalized geologic section of Washington County

	Feet
Carboniferous	
Permian (Dunkard series)	
Greene group	425
Nineveh coal	
Nineveh limestone	
Claysville limestone	
Dunkard coal	
Prosperity limestone	
Tenmile coal	
Donley limestone	
Upper Washington coal	
Washington group	400
Upper Washington limestone	
Jollytown limestone	
Jollytown coal	
Middle Washington limestone	
Blacksville limestone	
Lower Washington limestone	
Washington coal	
Little Washington coal	
Waynesburg "B" coal	
Colvin Run limestone	
Waynesburg "A" coal	
Mount Morris limestone	
Waynesburg sandstone	
Cassville shale	
Pennsylvanian	
Monongahela group	360
Waynesburg coal	
Monongahela group—Continued	
Waynesburg limestone	
Little Waynesburg coal	
Uniontown sandstone	
Uniontown coal	
Uniontown limestone	
Benwood (Great) limestone	
Bulger limestone	
Dinsmore limestone	
Sewickley coal	
Fishpot (Sewickley) limestone	
Redstone coal	
Redstone limestone	
Pittsburgh sandstone	
Pittsburgh coal	
Conemaugh group	500
Little Pittsburgh coal	
Lower Pittsburgh limestone	
Connellsville sandstone	
Little Clarksburg limestone	
Morgantown sandstone	
Barton (Elk Lick) coal	
Barton (Elk Lick) clay	
Birmingham shale	
Duquesne (Berlin) coal	
Ames limestone	
Harlem (Friendsville) coal	
Saltsburg sandstone	
Bakerstown coal	
Brush Creek coal	
Mahoning sandstone	

The above section does not include all of the strata present in Washington County but only those that are fairly persistent and recognizable over considerable areas or those of some economic importance. The strata named comprise only a minor portion of those present, the bulk of the rocks consisting of unnamed shales and sandstones as well as many thin limestone beds. Also it must be borne in mind that few of the named beds extend over the entire county either as outcropping or concealed beds.

All of Washington County has been mapped since 1901 by the U. S. Geological Survey and the results published in Folios Nos. 94, 144, 146, 177 and 180. The above section and much of the data that

follow have been compiled from these folios and Bulletins Nos. 65 and 249 of the same survey and Report K of the Second Geological Survey of Pennsylvania, supplemented by brief investigations by the author in 1921 and 1929. These publications contain much information that cannot be incorporated in this report.

Distribution of the geological formations. Reference to the geologic maps in the above-mentioned folios shows that the outcrop of the Conemaugh formation, the lowest in the county, is confined to the stream valleys in the northwestern part of the county, north of Washington, and to various places along the Monongahela River and the lower portion of its tributaries. Elsewhere the formation is concealed by younger strata.

The Monongahela group appears at the surface in the northern and eastern portions of the county. It appears in the stream valleys almost as far south as Washington and forms a broad band in the Monongahela River Valley that extends westward in the tributary valleys to the vicinity of Benningsville, Emery, Vanceville, Three and Four, Beallsville, and Zollarsville.

The Washington group appears on the divides in the northwestern portion of the county as far south as Washington and in a wide band extending through Somerset and West Bethlehem townships. In addition, it appears in most of the stream valleys in the southwestern porion of the county.

The Greene group, the youngest of the Carboniferous strata, forms the surface rocks, except in the deeper stream valleys, of practically the entire area southwest and south of Washington.

LIMESTONES OF THE CONEMAUGH GROUP

Ames limestone. The lowest limestone outcropping in Washington County is the Ames which has also been known as the "Green Fossiliferous" and the "Crinoidal" limestone. It is a greenish-gray, impure, gnarly limestone containing abundant fossils, mainly crinoid stems and brachiopods, indicating its marine origin. It weathers to a dull gray. It is rarely more than 2 feet thick but in a few places it occurs in two benches with a total thickness of 8 feet. It has a very limited exposure in Washington County, the outcrops being mainly confined to the northwest portion of the county, where it appears in the valleys of Aunt Clara Fork of Kings Creek, Kings Creek, and Harmon Creek, and is probably exposed along Monongahela River in the vicinity of Charleroi. It is of no economic importance.

Little Clarksburg and Lower Pittsburgh limestones. In the upper part of the Conemaugh group exposed in the northwestern part of the county, there are several thin discontinuous limestones, two of which have received distinct names. They are of little or no value.

LIMESTONES OF THE MONONGAHELA GROUP

Redstone and Fishpot (Sewickley) limestones. In several places the interval between the Pittsburgh and Redstone coals consists of limestones interbedded with shales. This is particularly true in the vicinity of Bulger. These limestones have been grouped under the name of the Redstone limestone. The stone is a high silica, high magnesian, argillaceous limestone of no value except for agricultural lime and of

little value for that purpose. It has a dense non-crystalline appearance not unlike flint fire clay. On weathering it breaks into small angular fragments showing conchoidal fracture.

The Fishpot or Sewickley limestone is a discontinuous limestone lens that is locally developed beneath the Sewickley coal. It is of little importance in Washington County.

Benwood (Great) and Uniontown limestones. "Above the Sewickley coal is a series of strata (9, p. 4), aggregating in places 160 feet, which was formerly called the 'Great limestone'; later, in accordance with the system of using geographic terms to designate geologic divisions, it was named the Benwood limestone, from the town of Benwood, W. Va., a short distance below Wheeling. The name Benwood was later restricted to the lower limestones of this interval and the name Uniontown, already in the literature, was retained for the upper limestone. It is in the restricted sense that Benwood is here used. Between the Benwood and Uniontown limestone members is a shale interval of 15 to 20 feet.

"In the Burgettstown and Carnegie quadrangles the Benwood member consists of several beds of limestone separated by thick layers of shale. To two of these limestone beds, which are valuable oil horizon markers, Griswold has given geographic names. The lower bed, of cream-white limestone, which lies 35 feet above the Sewickley coal, he has called Dinsmore, from exposures at Dinsmore, Washington County, Pa. The upper brown limestone bed he has called Bulger, from typical exposures at Bulger, Washington County. The Dinsmore limestone bed has a thickness of 4 feet and the Bulger limestone bed a thickness of 1 to 2 feet. These two limestone beds are separated by about 20 feet of shale, olive green at the top and reddish or yellowish below.

"Above the Benwood, separated therefrom by 15 to 20 feet of coarse calcareous shale, lies the Uniontown limestone member, of which four separate beds can generally be identified, though none of them are well developed in these quadrangles. The first consists of about a foot of solid limestone, which shows a yellow surface when weathered and is blue when freshly broken; the weathered surface always shows small protuberances, due to the presence of particles that are more resistant than the surrounding matrix, which give it the appearance of being covered with small pimples and make it easily recognizable. Ten feet above this limestone is another, about a foot thick; it is composed of two highly different materials, which on weathering produce a characteristic spotted surface which serves to identify the rock wherever found. From 16 to 18 feet above the last-mentioned bed is a blue limestone which on weathering has a white residue of clay upon its surface but is nevertheless easily distinguishable from other white limestone because the blue generally shows through the surface color. A foot or so above this bed is the top stratum of the Uniontown limestone member. On weathered outcrops, this is a soft yellow limestone, but on fresh fracture it shows brownish red. It disintegrates readily and is seldom found in a solid ledge, its outcrop usually being marked by the presence of brown limestone nodules."

These limestones are exposed in numerous places north of Washington. The top layers form the bed of Georges Run from Gretna to its mouth. They are exposed along Brush Run and Buffalo Creek in

Hopewell and Blaine townships and at the mouth of Buck Creek, south of Acheson. At the Arden mines, about 3 miles north of Washington, a shaft passed through 51 feet of limestone. In Folio No. 180 of the U. S. Geological Survey the following section of the Uniontown limestone is given (10, p. 5).

Section of Uniontown limestone member on road west from mouth of Georges Run in Canton Township, Washington County

	Ft.	In.
Limestone, dark blue, very hard, weathers yellowish white	1	4
Shale, yellow	2	0
Limestone, yellow and hard, very impure	2	6
Limestone, steel gray, weathers yellowish to white	0	6
Shale, yellow	8	0
Limestone, yellow	0	3
Shale, yellowish	8	6
Limestone, buff, very hard, weathers black	2	6
Sandstone, thin bedded	3	0
Limestone, in several beds, steel gray; top bed pimply; bottom bed weathers in grooves and fantastic forms to yellowish-white color	3	0
	31	7

The Benwood is exposed in ravines northeast of Kammerer, in eastern Nottingham Township, in Union Township and in many other places.

These limestones are generally high in silica, magnesium carbonate and argillaceous matter so that they are poorly adapted for flux, Portland cement, high grade lime, or for road metal. They have, however, been used locally for agricultural lime, for flux, in Fayette County for natural cement, and in various places stone of sufficient hardness for road metal has been obtained. For none of these uses, however, are they particularly well fitted and the bulk of the stone is of practically no economic value.

Analyses of Benwood limestone from Washington County

	1	2	3	4
$CaCO_3$	68.837	48.823	47.080	47.750
$MgCO_3$	14.649	20.621	28.528	30.943
$FeCO_3$ } Al_2O_3 }	3.306	3.625 / 3.523	7.511	5.608
S	.097	.203	.069	.126
P	.049	.051	.127	.015
Insoluble residue	13.300	22.520	15.750	14.920

1. One mile north of Canonsburg: Upper layer, very hard and compact, like conglomerate, bluish gray.
2. One mile north of Canonsburg: Middle layer, compact, somewhat shaly, color bluish gray.
3. One mile north of Canonsburg: Lower layer, hard, compact, unctuous pearl gray.
4. Property of Dr. Shaner, in Somerset Township, 8 miles from Washington.

Analyses quoted from 3, p. 285.

LIMESTONES OF THE WASHINGTON GROUP

Waynesburg limestone. The Waynesburg limestone outcrops in various parts of the county but especially in the southeast. It occurs from 40 to 60 feet below the Waynesburg coal, and has a maximum thickness of about 20 feet and a minimum of about 4 feet. It contains some good stone.

Mount Morris and Colvin Run limestones. Below the Waynesburg "A" coal is the Mount Morris limestone; between the Waynesburg "A" and "B" coals is the Colvin Run limestone; and above the "B" coal there are other thin beds of limestone not named. All of these are local and where developed are thin and of no importance except to yield a few tons for local use at or near the outcrop.

Lower Washington limestone. "The lowest (7, p. 7) of the three principal limestones outcropping near Washington, and named after that town, generally forms the roof of the Washington coal. Occasionally, however, a few feet of shale intervene between the coal and the limestone. The Lower Washington limestone occurs from 150 to 220 feet below the top of the Upper Washington limestone. Washington County is the region of its best development, and here it sometimes attains a thickness of 30 feet. It is generally interstratified with much shale, as shown in the following section:

Section of Lower Washington limestone and associated shale on Smith Run

	Ft.	*In*
Limestone	9	6
Shale, black		5
Limestone		7
Shale, black		4
Limestone		1
Shale, black and soft		2
Limestone		2
Shale, black		2
Limestone, hard, blue-black, weathers white		9
Shale, soft, black	2	0
Fireclay shale, dark		4
Bony coal		2
Shale, black		4
Fireclay shale, dark		5
Total	15	5

"The Lower Washington is at most places a hard, compact limestone, which has a light blue-gray to fleshy color and usually weathers bluish white. The color is not distinctive, and in general it can be said that the color of none of the limestones in the Dunkard formation is a certain guide to the identity of the bed. The colors mentioned are characteristic, however, and usually assist in identification."

Blacksville limestone. White (4) describes as the Blacksville limestone a generally gray, rather pure limestone from 3 to 5 feet thick that is fairly persistent throughout portions of Washington County from 30 to 50 feet above the Washington coal. It is difficult to recognize in most sections.

Middle Washington limestone. "Above the lower Washington limestone (7, p. 7) occurs a thickness of 60 to 100 feet of shales, and shaly sandstones. Occasionally this interval contains a thin bed of limestone. In places prominent sandstone beds occur locally. At the top of this interval and 100 to 140 feet below the Upper Washington limestone another bed of limestone generally occurs. It is a hard, compact, light-grayish or flesh-colored limestone, usually coarsely brecciated and containing numerous spots of crystalline calcite. This limestone

generally can be recognized by the great quantity of iron it contains, which gives it a bright-yellow weathered surface. The weathered part frequently extends to a depth of several inches, and finally exfoliates and crumbles off. Some of the basal layers are more earthy and slaty and do not have this characteristic. The bed is in some places 10 to 20 feet thick. A trace of coal or black shale occurs at some localities in connection with the limestone.

"The Middle Washington limestone has a wide distribution in the county, but occurs in typical form near Washington. In a cut on the Baltimore and Ohio Railroad in the eastern part of the town the large yellow boulders from the bed are finely exposed. The upper or ferruginous part of the bed is richly fossiliferous, but the fossils are generally not identifiable. They are usually replaced by crystalline calcite and therefore can not be recognized on fresh fracture, and on the weathered surface their characteristics can not be determined. One of the best localities for fossils is the cut in the eastern part of Washington. Minute univalves and bryozoans and a diplodus-like tooth have been found here (Rept. K, p. 49)."

"The Middle Washington limestone (10, p. 6) attains its greatest development in Independence, Canton, and Hopewell townships, where it is between 25 and 30 feet thick. It outcrops well toward the tops of the hills in both these townships and eastward into Mount Pleasant and Chartiers townships. It is finely exposed about half a mile north of the corner of Hopewell, Mount Pleasant, and Canton townships, as shown in the following section:

Section of Middle Washington limestone member on road from Buffalo to Gretna

	Ft.	In.
Coal (Jollytown), shaly	0	6
Shale and sandstone	3	0
Limestone, yellow	0	3
Sandstone, reddish, and shale	10	0
Shale, soft, cream colored	5	0
Limestone, hard, blue	1	0
Limestone, slabby white	1	6
Shale	3	0
Limestone, gray, hard, and tough, fracturing flesh color	2	0
Shale	3	0
Limestone, single heavy yellowish bed, fractures flesh color with calcite crystals	2	0
Shale	2	0
Concealed		

"In Blaine, Buffalo and Donegal townships this limestone is always present in outcrop, though it is thinner than in the townships toward the north, being in few places more than 20 feet thick. The heavy yellow ledge near the middle is as a rule prominently exposed and serves as an unfailing geologic marker, ranging from 70 to 82 feet above the Washington coal. Toward the southwest corner of the quadrangle, (Claysville) near Good Intent, this limestone appears to be represented by two or three thin layers embedded in brown shale."

Jollytown limestone. "In accordance (7, p. 8) with the usage of Stevenson (1876) and Stone (1905) the term Jollytown limestone is applied to the limestone occurring above the Jollytown coal and 30 to

40 feet below the Upper Washington limestone. It is a hard, grayish, sometimes brecciated limestone, weathering light gray to dirty yellow, and is a good guide to the geology. It is at some places several feet thick, and appears below the Upper Washington limestone on most of the roads in the southwestern part of the county."

Upper Washington limestone. "The topmost bed of the Washington formation is the Upper Washington limestone, which, with the exception of the Waynesburg sandstone, is the most conspicuous and persistent member of the Dunkard group. For this reason it was chosen as the best horizon at which to subdivide the group into formations. It occurs 630 to 710 feet above the Pittsburgh coal and 280 to 400 feet above the Waynesburg coal. The variation is irregular, but in general the thinning of the interval from the Pittsburgh coal seems to be toward the northwest.

"The characteristics of the Upper Washington limestone are rather distinctive. It is hard, compact, and brittle, and is generally made up of a number of layers separated by thin beds of shale. Throughout the greater part of Washington County it consists, in its upper part, of a limestone which, on fresh fracture, is dark blue-gray, bluish black, or nearly black in color. Generally it contains drab and mottled layers. The rock as a rule is high in calcium carbonate. In some parts of the district it is easily recognized by its weathered surface, which is almost white, with a slight tinge of blue. It varies in thickness from 4 to 30 feet.

"The best exposures of this limestone are in the vicinity of Washington, where it reaches a thickness of nearly 36 feet. The tunnel of the Baltimore and Ohio Railroad 1 mile east of town cuts through the bed, exposing at its western end the section given below. The limestone is quarried at this place.

Section of Upper Washington limestone and associated rocks at tunnel 1 mile east of Washington

	Ft.	In.
Shale, dark, soapy	10	0
Sandstone, hard, mottled, medium grained, gray	0	11
Shale, black, sandy	1	9
Upper Washington limestone:		
Limestone, blue-black	2	3
Shale, black	0	2
Limestone, blue-black	0	10
Shale	0	4
Limestone, blue-black, brittle	1	10
Shale, black	2	2
Limestone, hard, gray and thin shale	5	4
Shale, soft, dark	0	6
Limestone, light brownish gray, very hard, to level of railroad	3	0
Total thickness of Upper Washington limestone	16	11

"On Cemetery Hill, in the southwestern part of Washington, the total thickness of the limestone is 30 feet, as shown in a section by Stevenson (Rept. K, p. 46). A good partial section of the limestone is exposed in a quarry one-half mile northeast of town, on the Williamsport Pike, where it is quarried and crushed for road metal. The lime-

stone is well exposed on all the roads leading out of Washington toward the east and south, and outcrops at many points in the Nineveh syncline in South Strabane, northern Amwell, and South Franklin townships. In this region great care is necessary to avoid confusing it with a similar limestone which occurs 100 to 300 feet higher in the series. This limestone is also dark blue to black in color, and in thickness and other characteristics seems to be almost the exact counterpart of the Upper Washington.

"A good exposure of the Upper Washington limestone occurs in a quarry on the hill just southeast of Washington. The bed is here 15 feet in thickness. On the uplands in the vicinity of Mount Wheeler the limestone is deeply buried, but it appears again for about a mile between Vankirk station and Chambers dam, and south of McCracken station is exposed along Bane Creek from 100 to 200 feet above the floor of the valley. In the vicinity of Amity, and in general throughout the southern part of Amwell Township, it is high on the hills. South of Tenmile Creek it is overlain by 200 to 400 feet of rock. Its outcrop extends along the valleys and ravines for the entire distance between Dunne station and Bissell.

"Throughout West Bethlehem Township there are many outcrops of the limestone, but they all occur high on the hills, so that they appear on the map as mere patches. In the vicinity of Scenery Hill they are somewhat more extensive. One of the most continuous exposures of the limestone is on a long ridge on which a road runs in a northeast-southwest direction about midway between Daniels and Plum runs, west of Beallsville. The bed here seems to be at least 30 feet thick and numerous fragments of dark blue-gray limestone appear for several miles near the top of the ridge. It has been quarried on a knob about a mile west of Beallsville and on the National Pike one-half mile northeast of Odell. Near by, on the same hill, the thickness of the limestone appears to be as great as 50 feet.

"Near the middle of the Upper Washington limestone occurs a dark layer which contains great numbers of litle bivalves and crustaceans. Fragments of mollusks also occur. The fossils are in general well preserved, but can rarely be broken out. This layer of the Upper Washington limestone gives a peculiar fetid odor when struck by a hammer."

"The Upper Washington limestone (10, p. 6) underlies the southwestern half of the county, except narrow areas along valleys of the larger streams. It is also barely above drainage level on Tenmile Creek east of Prosperity and is exposed on Short Creek only in the vicinity of Sparta. Up Tenmile Creek from Prosperity the outcrop of the Upper Washington limestone rises faster than the bed of the stream, and at the head of the valley it encircles the higher hills. It appears to be thickest at the type locality in the vicinity of Washington, thinning somewhat toward the northwest in Canton, Chartiers, Hopewell, and Independence townships. Southwest of Washington the lower portion of this limestone becomes variable and in places does not outcrop."

In 1929 some Upper Washington limestone was being quarried from a stream bed on the farm of William Hutchinson along a branch of Middle Wheeling Creek in the north part of West Finley Township. Several layers, 10 to 14 inches thick, separated by thin shale beds,

were worked. The stone is dove-colored to dark blue when fresh but becomes white on weathering. It breaks with a glassy fracture. The stone was being pulverized for farm use.

The same limestone was rather extensively quarried at one time along the Washington-Waynesburg cement road about 1½ miles south of Laboratory. The section is as follows:

Quarry 1½ miles south of Laboratory

	Ft.	*in.*
Shale		
Sandstone	1	8
Shale	6	
Shaly limestone	2	
Shale		2
Limestone		6
Shale	1	2
Limestone	1	2
Shale		1
Limestone	1	0
Shale		4
Limestone	1	4
Shale, grading downward into shaly limestone	1	2
Limestone, shaly at top, otherwise massive	2	0
Shale	1	0
Limestone		11
Shaly limestone		6
Limestone		7
Shaly limestone		3
Limestone, exposed	1	0

The limestone is dove-colored to dark bluish black. It breaks with a glassy fracture and weathers into rough irregular blocks. The quarry was worked for crushed stone.

On the top of the hill at Marianna, about 1½ miles northwest of Zollarsville, similar Upper Washington limestone was being worked in 1929 to obtain stone for the streets. The opening was about 18 feet deep and showed alternations of bluish-black to dove-colored limestones and shales. About half a mile south, on the south side of Tenmile Creek, the same beds were formerly worked on a large scale to obtain stone for the roads.

All the Washington limestones have been quarried for agricultural lime, pulverized stone for farm use or for road metal and crushed stone for construction. The Upper Washington is especially valuable for these purposes and has been widely used.

Analysis of Upper Washington limestone near Washington, Pa.

$CaCO_3$	72.866
$MgCO_3$	3.813
Al_2O_3, Fe_2O_3	2.929
S	.155
P	.061
Insoluble residue	17.380

Sample from middle of bed; hard, compact, bluish gray limestone; conchoidal fracture. (2, p. 388).

LIMESTONES OF THE GREENE GROUP

Donley limestone. "For the most widespread and uniform limestone (10, p. 7) in the Greene formation throughout the southwestern part of the county, the name Donley has been adopted. It is from 18 to 45 feet above the bottom of the formation, and is present where its horizon comes to the surface. In the vicinity of Donley, Donegal Township, a typical section shows this limestone in three or four layers having a total thickness of 5 or 6 feet. The characteristic feature is its dark, rusty, lichen-covered surface when weathered. The limestone is very hard and tough and fractures unevenly with a dark steel-gray to almost black color, having a very coarse grain and showing numerous calcite crystals. The bed is also distinguished by its peculiar jointing, which has a striking resemblance to that of dry mud, the blocks being irregular in shape and from 1 to 3 feet in diameter. The joints are usually very distinct, many of them being from 1 to 3 inches wide and filled with dark-red residual clay. The Donley limestone is generally overlain by a light-gray laminated sandstone, 15 to 20 feet thick which locally becomes massive."

D. M. Campsey has been recently working a quarry about 1¼ miles north of Claysville. The strata exposed in the quarry are shown in the section below:

Section in Campsey quarry, 1¼ miles north of Claysville

	Ft.	in.
Shale overburden	10-20	
Bluish gray limestone, apparently without fossils. Contains considerable argillaceous material in lower portion. Weather white	1	3
Massive limestone	2	0
Gray to black shale gradually passing into limestone below without any sharp break		9
Massive limestone, exposed	1	3

All of the limestones seem to crumble badly when exposed to weathering. The fresh rock breaks into angular blocks with sharp knife-like edges and shows a glassy fracture. The strata dip gently northeast, into the hill. The stone is pulverized and sold for agricultural purposes. In 1929 it was being sold for $5.00 per ton at the plant.

Prosperity limestone. "Above the Tenmile coal (10, p. 8) is a rusty-yellow limestone, having a maximum thickness of 10 or 12 feet, which has been named the Prosperity limestone, from the village of that name in Morris Township. The top of this limestone is from 100 to 115 feet above the top of the Upper Washington limestone. The top layers are in places light bluish, fracturing irregularly with a dark-gray to rusty-black color, and are very coarse grained. The other layers are dark gray to buff on fracturing. This limestone is fairly persistent in the southwestern part of the county, being present on all the hillsides in the vicinity of Pleasant Grove. Its heaviest outcrop is northeast of Pleasant Grove, along the top of the ridge between East Finley and South Franklin townships."

Claysville limestone. "From 205 to 225 feet above the base of the Greene formation is a limestone, separated into two layers by 6 to 8 feet of yellow shale. The top layer is 6 to 8 inches thick, bluish white,

and dark brown on fresh fractures. The bottom layer is here and there as much as 18 inches thick, weathers with a rough surface to a reddish or yellowish color, and is dark gray on fracture. This limestone underlies a considerable area in the southwestern part of the county. In the northern parts of East and West Finley and Morris townships it is rather a compact bed, from 6 to 8 feet thick, the top layers being heaviest and all having a dark-gray color."

Nineveh limestone. Capping many of the higher hills in Morris and East and West Finley townships, there is a bluish white to cream limestone a few feet beneath the Nineveh coal that is called the Nineveh limestone. It contains 2 or 3 massive layers that are quite hard and tough, and is 4 or 5 feet thick.

ECONOMIC IMPORTANCE

The limestones of Washington County, although abundant and varied, are in the main, of inferior grade and do not compare favorably with those of other portions of the State or of adjoining States. However, their accessibility permits them to be extensively used throughout the county for highway construction and for lime. Individual beds possess the desired composition for the manufacture of Portland cement and it may well be that detailed investigations may discover some places where good stone may be obtained in large enough quantities and at sufficiently low expense to justify the erection of a cement plant, although no such locality is known to the writer.

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Wayne County contains no limestones of economic importance although here and there some beds, containing appreciable amounts of calcium carbonate, have been called limestones and have been utilized locally to a small extent. The surface consolidated rocks all belong to the Catskill group with the exception of a small area in Clinton and Canaan townships where Pocono, Mauch Chunk and Pottsville strata are present. They consist of sandstones, conglomerates and shales. Glacial deposits conceal the consolidated beds in many places.

As in other places, the Catskill contains occasional interbedded conglomerates or breccias in which the cementing material is calcium carbonate. The most persistent stratum of this sort has received the name of Cherry Ridge limestone from its extensive development near the village of that name. White in his report on the geology of the county (1, pp. 65-66) described this limestone as follows:

"This is one of the most remarkable and persistent of the Catskill strata; extending over a large part of Wayne county, and the eastern pier of townships in Susquehanna county; always immediately under the sandstone, and in fact a part of it; for, while the average thickness of the calcareous part of the rock may be called 5 feet, it varies greatly, rising here and there into the sandstone beds, and the sand descending elsewhere into the limestone bed.

"In respect of the great area occupied by this limestone it differs essentially from all the other calcareous breccias, higher or lower in the series; for these all seem to be very local deposits, appearing and disappearing suddenly in short distances.

"But in respect of the amount of carbonate of lime in the rock it cannot be said to deserve the name of a limestone.

"It is an agglomerate of chips of slate or shale—fish bone fragments—pieces of fossilized wood—and often a large quantity of sand—all cemented together by lime.

"Analyses of Mr. McCreath at Harrisburg show how extreme are the variations:

Analyses of Cherry Ridge Limestone in Wayne County

	a	b	c	d
$CaCO_3$	64.392	19.785	17.696	11.196
$MgCO_3$	1.816	3.518	1.589	1.664
$Al_2O_3+Fe_2O_3$	4.145	8.903	4.432	4.988
SiO_2	28.800	65.470	75.220	80.950
P	0.050	0.095	0.034	0.036

a. Schneck's quarry, Cherry Ridge Township, Wayne County; specimens from the richest part of the rock.
b. Specimens from the poorest part of the rock.
c. d. J. Multen's land, Oregon Township, Wayne County.

"By carefully selecting the rock Mr. Schenck's kiln has turned out a fair farming lime, most of it slacking to a fine powder, although pieces refuse to slack, and there is some slag.

"The effect of a liberal use of it on the soil is reported to be greater than that of barn-yard manure. As similar rich parts of the outcrop ought to be discoverable in other parts of the region, and as loose

bowlders from its innumerable lines of outcrop lie scattered all over Wayne County, and the eastern part of Susquehanna County, the subject deserves the close attention of farmers.

"The solubility of the rock appears from the blackish brown appearance of its weathered surface; hence the bowlders are called nigger heads; and are from 2 feet to 10 feet in diameter; a proof of the massive solidity of the stratum.

"The more siliceous portions of the stratum are extremely hard, as the drillers discovered in cutting through it on the Jefferson Branch railroad line.

"Its black outcrop can be traced from the roadside near Cadjaw pond (1 mile S.W. from Honesdale) northward along the Lackawaxen and its tributary streams over the highland nearly to the New York State line;—southward from Cherry Ridge to the south line of the county; and from the Elk mountains, around which it runs in a black line, 8 feet to 10 feet thick, 600 feet to 700 feet below their summit, northward along the highlands nearly to Starucca."

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WESTMORELAND COUNTY

The limestones of Westmoreland County occur at a number of different horizons and are widespread throughout the county. There is scarcely a community that is deficient in limestone. The consequence of this general distribution is that scores, if not hundreds, of small quarries have been opened to obtain stone for local burning for agricultural lime. The limestones burned are almost invariably fairly high in their argillaceous content so that the lime produced is of little value except for fertilizing purposes and has been used otherwise to only a small extent. In addition to the argillaceous matter entering into the composition of the limestone strata, it is very common to find that most of the limestones described below consist of interbedded limestone and shale strata so that it would not be possible to work the quarries by steam or electric shovels. Although local limestone burning is now much less common than it was 50 years ago, nevertheless it has not died out altogether and in many communities small quantities of stone are quarried and burned in open heaps or occasionally in stone kilns. The proximity of coal has facilitated this local industry.

In addition to the use of limestone for lime there has been considerable local use of the limestones for road building and for structural purposes but always on a small scale with the exception of the Loyalhanna (Siliceous) limestone which as been quarried in several places on a large scale for railroad ballast and paving blocks.

Generalized geologic section of Westmoreland County

	Thickness in feet
Carboniferous	
Permian (Dunkard series)	
Washington group	140+
Washington limestones	
Washington coal	
Little Washington coal	
Colvin Run limestone	
Waynesburg "A" coal	
Mount Morris limestone	
Waynesburg sandstone	
Pennsylvanian	
Monongahela group	380
Waynesburg coal	
Little Waynesburg coal	
Waynesburg limestone	
Uniontown sandstone	
Uniontown coal	
Uniontown limestone	
Benwood (Great) limestone	
Sewickley sandstone	
Sewickley coal	
Fishpot (Sewickley) limestone	
Redstone coal	
Redstone limestone	
Pittsburgh sandstone	
Pittsburgh coal	
Conemaugh group	660
Pittsburgh limestones	
Connellsville sandstone	
Clarksburg limestone	
Morgantown sandstone	
Wellersburg (Elk Lick) coal and clay	
Wellersburg (Elk Lick) limestone	
Duquesne coal and clay	
Ames (Crinoidal) limestone	
Harlem coal	
Upper Bakerstown coal	
Conemaugh group—Continued	
Woods Run limestone	
Lower Bakerstown coal	
Saltsburg sandstone	
Pine Creek limestone	
Pine Creek coal	
Buffalo sandstone	
Brush Creek limestone	
Brush Creek coal	
Mahoning coal	
Mahoning sandstone	
Allegheny group	285
Upper Freeport coal	
Upper Freeport limestone	
Bolivar fire clay	
Lower Freeport coal	
Lower Freeport limestone	
Upper Kittanning coal	
Johnstown limestone (cement rock)	
Middle Kittanning coal	
Lower Kittanning coal	
Clarion (?) coal	
Brookville coal	
Pottsville series	
Homewood sandstone	
Mercer group	
Connoquenessing sandstone	
Sharon coal	
Mississippian	
Mauch Chunk series	250
Greenbrier (Mountain) limestone	
Loyalhanna (Siliceous) limestone	
Pocono series	400+
Burgoon sandstone	
Patton shale	
Devonian	
Catskill group	

In the section given above only the members of economic or of especial prominence are given as these are the only ones that have received names. The greater part of the stratigraphic column consists of unnamed shales and sandstones. For example, the Mauch Chunk and Pocono series consist mainly of shales and sandstones and in each series a single limestone member only has been designated by a name. There are also occasional lenses of limestone, some of which in restricted areas may be of some importance, that are likewise omitted in the section.

In the descriptions of the individual limestone members it is impossible to mention all of the localities where each occurs. Extremely detailed geological work would have to be done to furnish this information and the importance of these limestones has not seemed to warrant such investigation. Practically every one is more or less irregular so that it is not everywhere developed at the horizon where it should occur even though both the underlying and overlying members are present. Therefore in those places where surface debris covers the hill slopes, it would require considerable expense and effort to determine definitely whether one or another limestone actually existed. It is also difficult in places to identify particular limestones on account of their similarity.

LIMESTONES OF THE MISSISSIPPIAN SYSTEM

Loyalhanna (Siliceous) limestone. The oldest limestone in Westmoreland County is the Loyalhanna, which has such a large siliceous content that it might more properly be termed a calcareous sandstone than a limestone. It has, however, been grouped with the limestones and is therefore described here. It consists of grains of silica cemented by calcium carbonate. It lies between the Mauch Chunk and Pocono series and is underlain by a big thickness of non-calcareous sandstone. At one time this bed was placed in the Mauch Chunk series. It is exposed only in Chestnut Ridge and Laurel Hill, both of which hills are pronounced upward folds (anticlines). Were it not for these sharp folds it would not appear at the surface. The best exposures are in the gorges produced by Conemaugh River and Loyalhanna Creek cutting through Chestnut Ridge and Laurel Hill.

This limestone has in the past been burned for lime in several places. The calcareous portion produced a white lime which slaked readily while grains of quartz remained unchanged. The burned product containing the lime and sand made a fair mortar. In recent years the sole use made of this stone has been for railroad ballast, paving blocks, and for highway construction.

One of the most characteristic features of the Loyalhanna is the prominent cross bedding, which is especially pronounced on weathered surfaces. On weathering, the calcareous cement is removed by solution and the resulting mass is practically pure quartz sand. Where fresh, the rock breaks with a conchoidal fracture and is light blue to gray in color. In places it contains some pyrite which readily oxidizes near the surface and produces a rusty brown discoloration. The rock occurs in massive beds and, when blasted, comes out in large blocks, which, however, can readily be split because of its brittle character. In thickness it varies from 40 to almost 80 feet in Westmoreland County.

Where Conemaugh River cuts through Laurel Ridge in the extreme northeast corner of the county, the Loyalhanna is about 50 feet thick. It is somewhat thicker in places where the same stream cuts through Chestnut Ridge. Here it has been worked on the Indiana County side (see description of the Loyalhanna in Indiana County) and on the Westmoreland County side by Booth and Flinn near Blairsville Intersection (Torrance P. O.). This is known as the Packsaddle quarry. This quarry was not visited by the writer but the information available indicates that it is practically the same as the Long Bridge operations. The Torrance plant has an annual capacity of about 40,000 tons of crushed stone.

Loyalhanna Creek, cutting through Chestnut Ridge and into the west slope of Laurel Hill, has exposed the Loyalhanna limestone and made conditions favorable for quarrying, especially in the gap through Chestnut Ridge. For a number of years, Booth and Flinn have operated an extensive quarry along Loyalhanna Creek at Long Bridge, about 1 mile northwest of McCance P. O. The calcareous portion worked is 50 to 55 feet thick and the quarry face is about half a mile long. Most of the stone is crushed for railroad ballast and for highway construction but some is made into paving blocks. The State Highway Department has accepted the finer stone for the State highways. The annual capacity of the plant is given as 100,000 tons of crushed stone.

The base of the Loyalhanna lies about 200 feet above the creek bed. The strata are almost flat but actually form a low anticline with gentle dips toward the ends of the cut. The stone is bluish gray in color, greatly crossbedded and so massive that true bedding planes are not readily observed in the quarry face. Vertical joints break across the beds and a few solution cavities were seen. Fossils were not observed, but quarrymen report that they are occasionally noted.

Immediately overlying the Loyalhanna limestone is a non-calcareous sandstone about 18 feet thick and still higher up is red shale with some greenish bands and sandstones and limestones of the Mauch Chunk group. The material stripped as overburden averages about 30 feet in thickness.

At times most of the material is sold for railroad ballast but at other times it may be used for the highways or for Belgian blocks. The railroad ballast is from 1 and 1½ to 3 inches in size. The Belgian blocks for paving are of two sizes. The small ones are 8 to 14 inches long, 4 to 5 inches wide and 5 to 5½ inches thick. The larger ones are 8 to 16 inches long, 3½ to 5 inches wide, and 6 to 7 inches thick. All of the chips from dressing the stone and the fine sizes screened from the railroad ballast material are used on the roads. The stone is hauled from quarry face to the crusher by trucks.

Analysis of composite sample of Loyalhanna limestone, Long Bridge

Pittsburgh Testing Laboratory, analyst

After drying at 105°C

SiO_2	49.54
Al_2O_3	3.44
Fe_2O_3	1.72
TiO_2	.30
CaO	24.80
MgO	.58
Loss on ignition	19.30
SO_3	trace

South of Loyalhanna Creek, there are several places where the same limestone has been worked in both Chestnut Ridge and Laurel Hill. In most places the quarries were small and furnished only a small amount of stone for burning. These have long since been abandoned. The only operation of consequence is that of the Westmoreland Blue Stone Co., which has an extensive quarry about 2 miles southeast of Whitney. The quarry is located at an elevation of about 1600 feet above sea level in the ridge bordering Arners Hollow on the south. The total thickness of the Loyalhanna exposed is about 60 feet and is said to extend 12 feet below the floor of the quarry. This statement could not be verified. The quarry face in 1929 was 620 feet long. The overburden is slight, less than 5 feet. The rocks are either flat or dip very gently to the west. The stone is practically the same as in the Booth and Flinn quarry at Long Bridge. It is gray and bluish gray.

The bulk of the stone is sold for ballast, but paving blocks are also made. At times 2000 blocks are made per day. The capacity is given as 50,000 tons of crushed stone and 200,000 tons of stone blocks.

An almost unlimited amount of Loyalhanna limestone is available in Westmoreland County but the operations must necessarily be confined to those localities where transportation facilities are favorable.

Greenbrier limestone. The Greenbrier limestone is of considerable importance in Westmoreland County, but less so than in Fayette County. It is a thin-bedded limestone, consisting of some layers of sufficiently good stone to furnish a good quality lime or hard enough to be used on the highways, interstratified with much shaly material that is practically worthless.

In Loyalhanna Gap, about half a mile above the water works at Kingston, the Greenbrier is only about 4 feet thick, and where Conemaugh River cuts Chestnut Ridge, it is about 5 feet thick. Just west of Bolivar it "is very impure, but it contains some layers, which would slake if carefully burned. When freshly exposed, it is very hard, but for the most part it soon breaks down under the influence of the weather. Fossils are numerous in several layers, and the specimens are well preserved" (3, p. 157). It increases in thickness rapidly to the southwest and, in a well one mile west of Walt's Mill on Sewickley Creek, appears to be 35 feet thick, along Jacobs Creek 40 feet, and continues to increase until in West Virginia it is several hundred feet thick. The Greenbrier outcrops along the sides of Chestnut Ridge and Laurel Hill but can seldom be found readily on account of the debris that covers these steep hillsides. It has been quarried in a small way in many places to obtain limestone for burning for agricultural lime.

Along Jacobs Creek in Mount Pleasant Township, Stevenson (3, p. 124) gives the following section and description:

Greenbrier limestone on Jacobs Creek

		Feet
1.	Limestone in thick layers	18
2.	Argillaceous limestone	20
3.	Compact limestone	2

"No. 1 is very pure and yields a lime which, for whiteness, compares favorably with any lime in the market. Mr. Freeman burns it extensively and it is sold to the farmers for use on their farms. Its effects on the land are very marked. The whole mass is fossiliferous, but specimens occur in greatest numbers in No. 2, which is in thin layers. The species are not numerous, but the specimens are fine and in prodigious quantity."

Along the west slope of Laurel Hill in Westmoreland County the Greenbrier is developed, although difficult to locate on account of the talus. It has been observed in several places in Cook Township. It is well exposed along Laurel Run, a branch of Whiteoak Run. Near the head of Powdermill Run it has been worked. "At one quarry a layer 7 feet thick is (has been) worked, but at Mr. Shawley's the limestone is in thin layers scattered through 40 feet of shale" (3, p. 126). Along Linn Run it has been quarried. "The pure formation is in all not far from 16 feet thick, and occurs in thin layers interstratified with calcareous shale" (3, p. 127).

LIMESTONES OF THE ALLEGHENY GROUP

Johnstown (Upper Kittanning) limestone—The Johnstown limestone, formerly known as the Johnstown Cement Bed because it was one time quarried at Johnstown for the manufacture of natural cement, is of little importance in Westmoreland County. It is chiefly developed in the Ligonier Valley between Laurel Hill and Chestnut Ridge. It is everywhere an argillaceous limestone, although in places where it is fairly thick some layers are of fair quality for the manufacture of agricultural lime. Along Whiteoak Run in Cook Township it was once quarried for lime burning even though the stone is decidedly impure. Along Laughlintown Run above Laughlintown it is probably as thick as in any part of the county. In one place where it was once quarried, a limestone bed 18 inches thick is separated from an underlying 9-inch limestone by 1 inch of shale.

"The upper bed is a compact layer, splitting so readily that posts of regular shape have been made from it, but it is of uneven composition, containing some thin and very hard layers, so that the weathered surface is grooved. This portion makes good lime but must be burned carefully. The lower portion is a massive dull gray to blue rock, evidently quite argillaceous, and containing great numbers of small mollusks. It contains also many lumps of limestone, which are clearly fragments of the Mountain (Greenbrier) limestone. This portion of the bed is burned into lime only with difficulty, as it tends to fuse" (3, p. 136).

It has also been quarried in other places in Ligonier Township, where it is only 4 feet thick and in some localities is entirely missing.

Along Conemaugh River above Lockport it is only about 1 foot thick and is a dark gray stone weathering to dirty white. Along Tubmill Run on the west slope of Laurel Hill it is about 1½ feet thick.

Lower Freeport limestone. The Lower Freeport limestone has not been widely recognized in Westmoreland County, but wherever developed, it appears to be high in iron. Along Conemaugh River above Lockport it is a ferruginous limestone varying from 2 to 4 feet in thickness. Along Tubmill Run on the west slope of Laurel Hill it is 3 feet

thick and is a compact ferruginous limestone weathering yellow. It is rather doubtful whether it has ever been quarried in the county.

Upper Freeport limestone. Throughout Westmoreland County the Upper Freeport limestone is developed in local areas. It is generally present in the Ligonier Valley and on the western slope of Chestnut Ridge. It varies greatly in thickness from place to place or completely disappears. It is commonly composed of thin limestone layers interstratified with shale beds Some of the limestone beds are fairly pure although generally they contain a rather high admixture of argillaceous matter. In the Ligonier Valley it has been quarried for lime in a number of places.

On Camp Run in Donegal Township it was once quarried at a place where it is 4 feet thick. Near Four Mile Run it is reported to be 11 feet in thickness and to have been quarried and burned for agricultural lime. It is partly a fair limestone but mainly argillaceous. Along Conemaugh River south of Lockport it is, in places, simply a layer of limestone nodules in shale, but elsewhere consists of three layers of ferruginous and argillaceous limestone aggregating 8 feet in thickness. Along Tubmill Creek near Factory School it was once quarried. Here the limestones and interbedded shales together are 14 feet thick.

Near the headwaters of Baldwin Creek in St. Clair Township the Upper Freeport is 3½ feet thick and has been quarried. It is "dark blue and slaty on top but light blue to cream colored and quite pure below." On Miller's Run in Derry Township it is 5 feet thick and was once quarried for lime. The upper portion is argillaceous, the lower fairly pure. Along the south side of Conemaugh River between Saltsburg and White, it is 3 to 5 feet thick and has been quarried and burned for agricultural lime. It is cream colored and argillaceous. Along Beaver Run in Bell Township it is reported to be 6 to 10 feet thick and was once quarried and burned.

In Report HHHH, of the Second Pennsylvania Geological Survey published in 1878, W. G. Platt gives the following data:

"The limestone has been but little worked in the vicinity of Saltsburg. It is exposed on the left bank of the Conemaugh River at Wining's salt works, showing there between 4 and 5 feet of excellent limestone that might profitably be quarried by the farmers and used as a fertilizing element. It is of a brownish color, semi-crystalline, and slakes easily, producing a good strong lime. The rock shows numerous impressions of minute shells."

Analyses of Upper Freeport limestones

	1	2
$CaCO_3$	91.982	94.643
$MgCO_3$	1.664	1.444
$Al_2O_3 + Fe_2O_3$	1.520	2.720
S	.091	.028
P	.012	.015
Insoluble residue	4.105	.990

1. Upper Freeport limestone, Wining and Cuisan's quarry, opposite Saltsburg, Westmoreland County.

2. Upper Freeport limestone, Kier Brothers' quarry, Salina, Westmoreland County. (4, p. 293).

LIMESTONES OF THE CONEMAUGH GROUP

Brush Creek limestone. The Brush Creek limestone was formerly called the Black Fossiliferous limestone because of its almost uniformly black color and the abundance of fossils which it contains. It is not continuous throughout Westmoreland County but has been recognized at a number of different places. It is always thin yet nevertheless it has been dug and burned into lime in several places. In Donegal Township in the southeastern corner of the county, it was once quarried along Indian Creek where the upper portion is a hard argillaceous limestone and the lower part a hard calcareous shale filled with fossil crinoid stems. It was also quarried near the head of Four Mile Run close to Donegal where it is 1¼ feet in thickness, and of fair quality, and also farther down the same stream. It is well filled with fossils. Along Zimmerman Run east of Ligonier in Ligonier Township it is so rich in iron that it is said to have been dug as iron ore at one time and shipped to Washington Furnace.

Johnson in his report on the Mineral Resources of the Greensburg Quadrangle (11, p. 65) gives the following descriptions.

"Associated always with a dark shale and occurring a few feet beneath the Buffalo sandstone is found usually the impure, easily weathered Brush Creek limestone. Because of its easy disintegration, it is difficult to trace in this region. It is abundantly fossiliferous and where found is stained dark by iron.

"Probably the best exposure of the Brush Creek limestone in the whole quadrangle is half a mile east of Eisaman at a tunnel in the bottom of the hill on the north side of Little Sewickley Creek. Here the following section was measured.

Section ½ mile east of Eisaman

	Ft.	*in.*
Shale, dark, fine-grained	10	
Limestone, (Brush Creek), fossiliferous, dark, badly weathered	1	
Clay-shale, black		2
Coal, clean	1	2
Shale		7

"In the Murrysville region this limestone is missing, but its horizon is represented by a fossiliferous shale occurring just above the Brush Creek coal."

Pine Creek limestone. The Pine Creek limestone has not been definitely recognized by most workers in Westmoreland County and is of little economic importance. Johnson gives (11, p. 64) the following descriptions of its occurrence within the limits of the Greensburg quadrangle where it is probably fairly typical.

"In the Greensburg quadrangle the Pine Creek limestone is found most persistently on the Murrysville anticline. There it is a light gray, hard, compact, fossiliferous limestone, and is an important key horizon. When weathered it frequently has a characteristic concave surface not exhibited by any of the other limestones in the Conemaugh group. Productus, crinoids, spirifers, and bryozoans are some of the fossils frequently seen. In that region the Pine Creek varies in thickness from four inches to two feet. Often the shale immediately above

the Pine Creek contains well preserved fossils. The average interval from the Pine Creek to the Upper Freeport coal is about 175 feet. The interval to the Ames is about the same.

"On the Grapeville anticline the Pine Creek limestone is less persistent and thinner and is much more difficult to trace. It was observed in few places and consequently could not be relied upon as a key rock in determining the structure of that area. It was found at several places on the Fayette anticline, but is thin and usually altered to a ferruginous clay where it outcrops.

"Frequently a coal ranging from a fraction of an inch to 16 inches thick occurs just beneath the Pine Creek limestone. The coal is of poor quality and for many years at least cannot be thought of as possessing any value.

"The Pine Creek limestone usually is underlain and overlain by soft shale. A thin bed of clay may lie beneath it, as in a typical section 1½ miles west of Murrysville.

Section 1½ miles west of Murrysville

	Ft.	in.
Shale, sandy and thin-bedded sandstone (Saltsburg)	50+	
Shale, drab, fissile	15	
Sandstone, thin-bedded, ferruginous, nodular, micaceous	5	
Concealed	10	
Limestone, Pine Creek	1	6
Shale	3	
Coal		
Clay	2	2"

Woods Run limestone. The Woods Run limestone has not been identified in many places in Westmoreland County. The best information available is contained in the following descriptions by Johnson of this formation as it is developed within the Greensburg quadrangle.

"So named because of its discovery and good exposure at Woods Run near Pittsburgh, this fossiliferous, marine limestone, typically thin and nodular, is found only in the western part of this quadrangle. Because of the characteristics mentioned the limestone has little value as a key rock in determining the stratigraphy, and no economic value.

"The limestone is usually impure, containing much clay, carbonaceous material and sand. In some places it is highly ferruginous. Locally thin coal or carbonaceous shale is found immediately beneath the limestone. Percy E. Raymond has listed some of the fossils found in the Woods Run in the Pittsburgh district in an article entitled, A Preliminary list of the fauna of the Allegheny and Conemaugh series in Western Pennsylvania.*

"The Woods Run limestone is found at intervals varying from 24 to 70 feet above the Pine Creek limestone. The usual interval is 50 feet. This is what has been defined previously as the Saltsburg horizon."

Ames (Crinoidal) limestone. The Ames limestone is a persistent though not continuous bed or series of beds widely distributed through-

*Raymond, Percy E., Preliminary list of the fauna of the Allegheny and Conemaugh series, in western Pennsylvania: Carnegie Mus., Annals, Vol. VII, pp. 144-158, 1910.

out Westmoreland County. Because of its greenish color and the abundance of marine fossils it can be more definitely recognized than any of the other limestones of the county with the exception of the Loyalhanna. The author did not have opportunity to investigate this member carefully nor have most geological workers in the region done more than incidentally refer to its presence here and there. Johnson, however, made a more detailed study of the Ames in the Greensburg quadrangle and the following paragraphs are taken from his report. (11, pp. 58-59).

"The appearance of the Ames limestone in this area is quite similar to the description given in former publications. It is typically a greenish-gray, rough-appearing marine limestone, which is always abundantly fossiliferous. Stratigraphically, it is the highest marine limestone in the quadrangle. It is fairly hard and compact, and when broken the fresh surface nearly always exhibits many sparkling calcite plates of broken crinoid stems. The weathered surface is rough with projecting crinoid stems and other fossils which resist weathering. Often the limestone consists almost entirely of crinoid stems and a jumbled mass of the beaks of *Ambocoelia planiconvexa*, a marine bivalve shellfish. *Lophophyllum profundum*, *Chonetes granulifer*, and other small marine shell-secreting animals are abundant. Many other species are more or less abundant depending on the locality. Where well developed the Ames usually occurs in two or three comparatively thin beds in close proximity seldom exceeding a total thickness of 30 inches. In most places it is a single bed 10 or 12 inches thick.

"Occurring near the middle of the Conemaugh and being easily recognized, the Ames limestone is a very important horizon marker in this quadrangle. The interval between the Ames and the Pittsburgh coal is not constant but varies slightly from point to point. By obtaining accurate measurements of this interval wherever possible, the true interval at any one point can be figured very closely, however. In general there is a thickening of the strata between the Ames and the Pittsburgh coal towards the southeast; so that whereas the interval is 280 feet near Murrysville, at Greensburg it is 340 feet.

"The following table gives the thickness of the Ames and the intervals to the Pittsburgh coal at different points.

Thickness of Ames limestone and distance below Pittsburgh coal

	Thickness *Ft.*	*Thickness* *in.*	*Interval* *Ft.*
South of Fosterville, near the Pennsylvania R. R., and just over the southern boundary of the quadrangle		3	345
¼ mile southwest of Middletown, Hempfield Township	2	8	325
On P. R. R. ¾ mile east of Penn Station	1		320
On P. R. R. ¼ mile east of Ardara Station	2		310
Quarry at Blackburn, Turtle Creek branch of P. R. R.	2	4	295
1 mile southeast of Newlonsburg, Franklin Township	1	6	280
Just south of Mamont cross-roads, Washington Township	2		290
2 miles south of Sardis, Franklin Township	1	6	300
¾ mile east of Delmont, Salem Township	1	4	300
1 mile west of northeast corner of quadrangle	1	4	300
3½ miles east of Boquet, Penn Township	1	2	320

"Although it has never been quarried anywhere on a large scale, the Ames limestone (11, pp. 132-133) in years past was quarried at many points by the farmers on whose properties it occurred, particularly along the Grapeville anticline in the south part of the quadrangle. It was so well thought of as a soil conditioner that several feet of cover were sometimes moved in order to recover only one foot or less of limestone. The limestone was not burned, as a rule, but was spread directly on the fields. The results obtained were most beneficial, according to report. One reason it is no longer being quarried except at a few isolated points, is because most of the easily available limestone has already been removed.

"Two samples of the Ames limestone were collected for analysis, one at a point three-fourths of a mile southeast of Fosterville, Hempfield Township, and a second in a cut of the Pennsylvania Railroad a quarter of a mile southeast of Ardara, North Huntingdon Township. Where the first sample was taken, the Ames occurs as a single bed, 10 inches thick. In the cut near Ardara, the Ames occurs as several beds of limestone of variable thickness, separated by thin and variable beds of limy, clay-shale. The total thickness of limestone and interbedded rock is 29 inches.

Analyses of Ames limestone

Pittsburgh Testing Laboratory, analyst

After drying at 105°C:

	1	2
SiO_2	20.60	9.00
Al_2O_3	8.98	1.99
Fe_2O_3	2.86	1.43
TiO_2	.40	.30
$CaCO_3$	58.97	79.44
$MgCO_3$	4.11	4.02
Loss on ignition (other than carbon dioxide)	1.37	None
Alkalies and undetermined	2.71	3.82"

In addition, the Ames has been reported from many other localities in the county including the following localities: 3½ miles east of Saltsburg, east of New Alexandria, in Washington Township, and in East Huntingdon Township.

Wellersburg (Elk Lick) limestone. A limestone has been found in several places a short distance below the Wellersburg (formerly called Elk Lick) coal. It has not positively been identified in many places so that little can be said concerning it other than it is similar to the other limestones of the Conemaugh group. It is argillaceous and interbedded with shales. It is probably the limestone that is present in two hills, Brant Knob and an unnamed one, about 3 miles southwest of Ligonier. It is present 1 mile southeast of Newlonsburg where it is 2 feet thick.

Clarksburg limestone. The Clarksburg limestone has not been differentiated from the other limestones of the Conemaugh group in most parts of Westmoreland County and this can only be done by detailed investigations. Within the Greensburg quadrangle Johnson has made such studies and has given the following descriptions. (11, pp. 52-53.)

"At an interval varying from 100 to 160 feet below the base of the Pittsburgh coal (interval increases from west to east) there is nearly always found a limestone bed or group of beds which has been termed Clarksburg limestone in conformance with previous nomenclature. The Clarksburg limestone beds are as a rule, compact, light-gray, or blue-gray in color, more nearly pure than the average fresh-water limestone, and often contain fresh water fossils. They break with a smooth, conchoidal fracture, and the fresh surface usually shows many small, sparkling, calcite crystals.

"The Clarksburg limestone is much thicker in the southeastern part of the quadrangle than elsewhere. The following sections illustrate its thickness and character at different points in the quadrangle.

Section 2 miles south of Plum Creek Church

	Feet
Shale and sandy shale	40
Limestone, pure, mottled, dove colored and showing scattered calcite crystals on fresh fracture, Clarksburg	2
Sandstone and sandy shale	45

Section in cut of the Pennsylvania Railroad at Radebaugh

	Ft.	in.
Shale, gray, sandy	14	
Coal, bony, Little Clarksburg		2 to 12
Shale, sandy	1	6
Limestone, light-gray, Clarksburg		6
Shale, dark-gray	1	
Limestone, blue-gray, calcite crystals, Clarksburg	2	
Shale, gray, fissile	5	
Limestone, gray, partly weathered to a rusty color, Clarksburg	4	
Shale, variegated, limestone nodules	15	
Shale finely laminated	4	
Limestone, gray, rusty, Clarksburg	3	
Shale, gray, fissile, limestone, nodules	4	
Limestone, gray, nodular, Clarksburg	2	
Shale, gray, limy	4	
Limestone, light-gray, Clarksburg		6
Shale and sandy shale		

Section 2½ miles north of Delmont

	Feet
Sandstone, shaly, thin-bedded	22
Shale, sandy	2
Limestone, 2 beds, upper containing many spirorbis, Clarksburg	2
Shale, greenish-gray, poorly stratified	10

Section 1 mile northwest of Irwin

	Feet
Shale, red	10
Limestone, Clarksburg	2
Sandstone, massive	10+"

"The Clarksburg limestone (11, pp. 131-132) is best developed in the region southwest and south of Greensburg where it attains a maximum development of about five feet. In other parts of the quad-

rangle the beds are thin and separated by beds of shale and clay five feet or more thick, so that quarrying the limestone is not feasible.

"A sample was cut from the limestone beds exposed in an abandoned quarry one-half mile south of Fosterville, Hempfield Township. The section exposed there is as follows:

Section half a mile south of Fosterville

	Ft.	in.
Sandstone, Connellsville	11	
Shale, sandy	2	6
Clay, gray	1	6
Limestone, shaly, yellow		6
Limestone, compact	1	10
Limestone, shaly		3½
Limestone, compact	2	1½
Clay		

"The analysis of the sample shows that it is suitable for road metal or for use as a soil sweetener.

Analysis of Clarksburg limestone

SiO_2	8.04
Al_2O_3	2.01
Fe_2O_3	1.43
TiO_2	Trace
$CaCO_3$	82.20
$MgCO_3$	5.35
Loss on ignition (other than carbon dioxide)	1.01"

Pittsburgh limestones. Beneath the Pittsburgh coal there are a number of limestone lenses interbedded with sandstones, shales and some thin coal beds extending downward through a thickness of nearly 100 feet. These have resulted in considerable confusion. The limestone stratum which lies within a few feet of the Pittsburgh coal has been called the Pittsburgh or Upper Pittsburgh and a lower limestone horizon has been termed Lower or Little Pittsburgh.

In Westmoreland County the uppermost of these limestones seems to be of practically no economic importance. Johnson describes it as "ordinarily a dark, impure, nodular limestone, commonly less than one foot thick." He discusses the Lower Pittsburgh limestones of the Greensburg quadrangle in the following paragraphs. (11, pp. 49-52.)

"The name Lower Pittsburgh has been given by various geologists to a limestone bed occurring between the Upper Pittsburgh limestone and the Clarksburg limestone, but since as many as six limestone beds have been found in that interval, the use of the name is ambiguous. The character of these beds changes considerably from point to point, but at one place it will be noted that the limestones increase in purity with an increase in their distance from the Pittsburgh coal above. The limestones close to the coal may contain a small number of ferruginous concretions. Minute, snail-like fossils (spirorbis) are common in the Pittsburgh limestones in some places. At any one point they are usually confined to one or two of the beds.

"Quite commonly in the northwestern, central and southern parts of the quadrangle a very massive limestone bed is found 20 to 40 feet

below the base of the Pittsburgh coal. This limestone weathers to a characteristic buff color with rusty iron streaks. In the southern part of the quadrangle it is five feet thick in places.

"In the northeastern part of the quadrangle the Pittsburgh limestones are quite replaced by sandstone."

"This limestone (Lower Pittsburgh) (11, p. 131) is best developed south of the main line of the Pennsylvania Railroad, although it also occurs in the northwestern part of the quadrangle. Occurring usually in several beds, the particular limestone bed referred to is the dense, thick bed occurring from 20 to 40 feet beneath the base of the Pittsburgh coal. In many places this bed is four feet thick and nearly everywhere it is over three feet thick in the area mentioned. It has been quarried quite extensively by the farmers in whose fields it outcrops and the lime obtained by burning it is regarded very highly.

"At a point about three-fourths of a mile northwest of Arona, on the W. A. Bussard farm, the limestone was mined by drift on a small scale. The bed at this point is 4½ to 5 feet thick and is immediately overlain by the Lower Pittsburgh sandstone."

In 1929 S. Panzeca was engaged in quarrying the Pittsburgh limestone about one mile north of Arona to burn for use on his own farm. At times he has quarried and sold limestone to his neighbors.

Section at Panzeca quarry

	Ft.	*in.*
Sandstone, some of which has been quarried ..	10-20	
Greenish shale	5	
Conglomeratic limestone discolored by iron ...		11
More massive limestone	1	5
Thick-bedded blue limestone	2	6

It is said that another layer of limestone lies beneath but is not now exposed.

Analysis of Lower Pittsburgh limestone

Pittsburgh Testing Laboratory, analyst

After drying at 105°C:

	1	2
SiO_2	6.64	5.68
Al_2O_3	1.64	1.68
Fe_2O_3	1.72	2.72
TiO_2	trace	trace
$CaCO_3$	82.76	81.31
$MgCO_3$	4.64	5.65
Loss on ignition (other than CO_2)	1.46	1.69
Alkalies and undetermined	1.14	1.27

1. Sample taken in a cut of the Hempfield Branch, Pennsylvania Railroad, three-fourths of a mile east-northeast of Pennine, Hempfield township. The limestone bed measured 54 inches thick, the bottom 6 inches being somewhat shaly.
2. Sample taken in a cut of the Pennsylvania Railroad a third of a mile west of Irwin. Limestone bed 55 inches thick." (11, p. 131)

In Ligonier and Fairfield townships, limestones of the Lower Pittsburgh horizon are developed and reach a thickness of 4 to 8 feet. They have been quarried for lime in a number of places and produced a good quality lime. In the hill south of Ligonier and in other places in that vicinity, the limestone is 8 feet thick and has been quarried

for lime burning. It has also been utilized in a number of places in the high ground between Loyalhanna Creek and Conemaugh River.

In addition to the specifically named localities where the Pittsburgh limestones have been described, there are undoubtedly many other places where they occur.

LIMESTONES OF THE MONONGAHELA GROUP

Redstone limestone. Johnson has given the following descriptions of the Redstone limestone in the Greensburg quadrangle. (11, pp. 35-36).

"The Redstone limestone, occurring close beneath the Redstone coal, is a rather persistent, fresh water, compact, brittle limestone which increases in thickness and importance from west to east.

"Where it is thick, and in all regions where the Redstone coal is missing but the limestone present, the latter is usually pure and compact, breaks with a smooth conchoidal fracture, and is often characterized by small, sparkling calcite crystals on the broken rock.

"In the Irwin basin, where the Redstone coal is thick, the Redstone limestone is thin or missing; and where the coal thins out towards the north, the limestone becomes more prominent. Thus, in the southwest corner of the quadrangle we find 3½ to 4 feet of coal and only scattered limestone nodules in the clay beneath it; whereas at Irwin, where the coal is thin and sometimes only represented by a thin, carbonaceous shale, the limestone measures from one to two feet.

"A section of the Redstone horizon (the coal has been cut out by the Sewickley sandstone above) was measured at an exposure near the western edge of the town of Irwin.

Section at west edge of Irwin

	Ft.	*in.*
Sandstone, massive, cross-bedded, medium grained, unconformity at base	20+	
Clay, gray with limestone nodules	3	
Clay, yellow limy	2	6
Limestone, light gray, smooth facture, Redstone	1	8
Clay with limestone nodules—grades into shale at base	4	
Sandstone, thin, hard, gray, close-grained	1	6
Shale, gray to greenish-gray, sandy	6+	"

"Near Penn Station the Redstone limestone varies from zero to eight or ten feet thick, depending on whether or not erosion cut it down before the deposition of the Sewickley sandstone. Near Greensburg it attains its maximum development in this quadrangle.

Section 1½ miles east of Greensburg

	Ft.	*in.*
Wash	2	
Limestone, much jointed, conchoidal fracture ..	1	
Shale, limy, and clay	2	6
Clay-shale with bluish-gray fire clay parting ..		6
Clay, rusty, limy	1	
Limestone, massive, conglomeritic weathers rusty	4	6
Limestone, soft, weathered		6+"

Section at Huff, Keystone Clay Products Co. mine

	Ft.	in.
Shale, dark gray	16	
Fire clay, gritty	2	
Shale, black, coaly		4
Coal, Redstone	4	4
Fire clay, light gray	2	
Limestone	12	
Clay-shale	3	
Shales, sandy	20	

"Of little importance in the western and northern parts of the quadrangle, the Redstone limestone (11, pp. 130-131) becomes of increasing importance towards the southeast. There it is quarried at several points for use as road metal and as a source of lime. Where it is thick and where the Redstone coal is thin or wanting, the Redstone limestone is hard and compact and usually quite pure. Although not known to have been quarried in this quadrangle for such a purpose, farther south it has been used largely for flux. Many available quarry sites are to be found along its extended outcrop in the Greensburg syncline.

Analyses of Redstone limestone

Pittsburgh Testing Laboratory, analyst

After drying at 105°C.	1	2
SiO_2	5.04	11.36
Al_2O_3	1.77	2.57
Fe_2O_3	2.15	1.43
TiO_2	trace	.20
$CaCO_3$	81.84	79.35
$MgCO_3$	5.11	2.95
Loss on ignition (other than CO_2)	.66	.18
Alkalies and undetermined	3.43	1.96

1. Sample taken from a 28-inch limestone bed occurring 7 feet below the base of the Redstone coal at the quarry of the Keystone Clay Products Company, one-fourth of a mile north of Huff, Hempfield Township.
2. Sample taken from a 19-inch bed exposed in a cut of the Pennsylvania Railroad, 350 yards east of the Irwin station."

The Redstone limestone is not limited to the Greensburg quadrangle but occurs in many places elsewhere in the county. It has not been studied in detail nor has it been differentiated from the other Carboniferous limestones. In Ligonier Township it appears in the vicinity of the Myers School, where it is about 4 feet thick and has been quarried on several farms. The better layers yield a fair grade agricultural lime. The stone is blue to dark brown when fresh, but rusty on weathered surface due to its high ferruginous content. In some places in East Huntingdon Township it is 2 to 7 feet in thickness.

Fishpot (Sewickley) limestone. The Fishpot limestone as developed in the Greensburg quadrangle is described by Johnson in the following paragraphs. (11, p. 33)

"Just south of Carbon the Fishpot limestone occurs in the interval between the Sewickley and Redstone coals. Although the limestone is there twelve feet thick, it thins rapidly in every direction, and this is the only locality in the quadrangle where it is more than two or three feet thick. The following section was measured where the road run-

ning south from Carbon passes over the tracks of the Pennsylvania Railroad cut-off:

Section at Carbon

	Ft.	in.
Shale, brown	12	
Shale, carbonaceous (Sewickley coal horizon)	1	8
Limestone	5	6
Clay, ferruginous	2	
Shale	1	
Limestone, very massive	3	6
Limestone, soft, yellow	3	
Clay		6
Concealed	9	
Coal, Redstone	2+	"

"The Fishpot limestone (11, p. 130) is of importance only in the vicinity of Carbon, Hempfield Township. In order to determine its qualities, a sample was taken where the limestone is exposed in the cut of the Pennsylvania Railroad cut-off at the south edge of the village. The limestone beds sampled totaled nine feet thick.

Analysis of Fishpot limestone

Pittsburgh Testing Laboratory, analyst

After drying at 105°C:

SiO_2	9.04
Al_2O_3	2.85
Fe_2O_3	2.15
TiO_2	.20
$CaCO_3$	72.81
$MgCO_3$	8.67
Loss on ignition (other than CO_2)	2.26
Alkalies and undetermined	2.02"

Elsewhere in the county, the Fishpot limestone has not been distinguished from the other limestones of similar characteristics. An 8-foot bed between Myers School and Mill Creek in Ligonier Township has been referred to this horizon. It is a ferruginous blue to dark brown limestone and has been utilized for agricultural lime. Near Smithton a 20-foot limestone, mainly of good quality but in part ferruginous and argillaceous, has likewise been termed the Fishpot. It is also present at Port Royal.

Benwood and Uniontown limestones. Johnson's detailed descriptions of the Benwood and Uniontown limestones, formerly known as the "Great Limestone", given for the Greensburg quadrangle, are quoted as follows: (11, pp. 28-30)

"Directly beneath the Uniontown coal, or separated from it by only a few feet of shale, is a limestone bed, the uppermost of many limestone beds which for the sake of convenience have all been grouped together and called Benwood limestone. By this term we designate all those beds between the Sewickley sandstone (or Sewickley coal when present) and the Uniontown coal. This in places represents a total thickness of 170 feet of limestone, shale, sandstone and clay. Usually the limestone beds are in two groups separated by shale and sandstone. The upper group of limestone beds has received the name Uniontown limestone. Due to the fact that the limestone beds weather more easily than some of the rocks above and below, it was found impossible to obtain a complete section. Such sections as were obtained seem to indicate much variation in the various beds, both in thickness and distinguishing characteristics.

"As shown in the accompanying sections, the two groups of limestone beds in the Benwood are not massive, thick limestone, but consist rather of many individual beds, separated by shale or clay. Well drillers invariably report the Benwood as one, or possibly two, massive limestone beds, 30 or more feet thick. This has tended to give a rather erroneous impression of the true character of the Benwood.

Section of upper part of Benwood limestone as exposed in railroad cut at Herminie

	Ft.	in.
Wash	5+	
Limestone, cream gray		10
Shale, drab	1	
Limestone, massive, gray, weathered cream color	2	6
Shale, gray paper	6	
Limestone, massive	2	3
Clay shale	1	
Limestone, cream gray	1	6
Clay shale		6
Limestone, cream gray	1	3
Clay shale		3
Limestone, cream gray	2	7
Shale, soft		6
Limestone, cream gray	1	10
Shale, soft	1	
Limestone	2	3

Section of upper part of Benwood limestone in a cut of the Youghiogheny branch of the P. R. R. ¾ mi. southwest of Rillton

	Ft.	in.
Sandstone, thin bedded	5+	
Limestone, dark gray shaly (top of Benwood)		10
Limestone, light gray to cream gray	5	
Shale, gray to clay-shale	5	
Limestone, massive, cream color beds	4	
Shale, gray to brown	3	6
Limestone, soft, yellow	2	3
Shale	1	
Limestone, gray to cream color	12	
Shale, greenish-gray	3+	

Section of Benwood limestone in first and second cuts east of Greensburg along the P. R. R. tracks

	Ft.	in.
Shale, fissile, weathered brown	14	
Limestone, soft, easily weathered, fossiliferous (fresh water)	8	
Limestone, massive, gray, weathers buff	2	
Limestone, shaly	4	
Shale, dark blue-gray fissile	7	6
Limestone, massive, gray weathering buff	15	
Limestone, massive, and dark gray shale	7	
Shale, limy	1	
Limestone, weathered deep buff	4	
Clay	2	6
Fireclay, dark gray		4
Shale, sandy, and shaly sandstone	5	
Shale, dark, slate-color, fissile gritty	6	
Limestone, compact, buff and gray	13	
Concealed	23	
Sandstone, massive, thick bedded, micaceous, rusty brown, light gray on fresh facture	66	

Section along road from Manor south to Lincoln Highway

	Ft.	in.
Coal, Waynesburg		
Sandstone, buff colored, fine grained	28	
Concealed	27	
Sandstone, coarse grained	10	
Sandstone, shaly	10	
Concealed	10	
Limestone	5	
Shale, sandy	4	6
Limestone (many beds)	30	
Concealed	15	
Limestone (several beds)	15	

Section south of Harrison City

	Ft.	in.
Shale, carbonaceous, Uniontown coal horizon	3	
Limestone, dark gray, carbonaceous		6
Clay	8	
Limestone, blue-gray	1	9
Clay		11
Limestone, dark gray		6
Clay		5
Limestone, mottled gray	1	6
Limestone, badly weathered	1	8
Concealed	6	
Limestone, yellow		8
Concealed (limestone boulders)	24	
Sandstone, greenish-yellow, micaceous	2	6
Concealed	7	6
Limestone, compact, hard	2	6
Concealed	7	6
Sandstone, greenish-gray, ripple marks near top	15	
Concealed	4	
Limestone, hard compact		8
Concealed	5	
Limestone (several beds)	10	
Concealed	5	
Limestone, dark bluish-gray		10
Clay drab	5+	

"The various limestone beds in the Benwood group vary from pure, blue gray limestone to dark gray, carbonaceous and soft, arenaceous limestone. Much of it is good enough to burn for lime and farmers have used it extensively for this purpose. At one or two points small fresh water fossils were observed.

"The Benwood limestone crops out over a large area in this quadrangle in both the Irwin and Greensburg synclines.

Distance between base of Benwood limestone and base of Pittsburgh coal

Location	Feet
Southwest corner of quadrangle	117
East of Irwin along P. R. R. tracks	125
Southwest of Harrison City	120
Lincoln Highway, Radebaugh to Greensburg	160
Northwest of Boquet	190
1 mile north of Hannastown	150

"Towards the north the Pittsburgh and Sewickley sandstones seem to thicken and the Benwood limestone becomes thinner so that the interval between it and the Pittsburgh coal increases from south to north."[2]

"The Benwood limestone (11, pp. 127-130) outcrops in a large area and has been used as a source of road metal and lime wherever it occurs. The beds vary greatly in composition and character but as a rule are sufficiently pure to make satisfactory lime when burned. Although kilns are sometimes used, the usual procedure in burning is to level off a spot about ten by fifteen feet and then build a pyramidal pile of alternate layers of coal and limestone. Wood is put at the bottom in order to ignite the mass. Once ignited, the pile is allowed to burn itself out and the material is then scattered over the fields. Naturally the resultant lime is far from pure and in many cases the larger chunks of limestone are only partly calcined. The farmers claim, however, that the results obtained when the lime is used on their fields, are equally as good as when pure, kiln-burnt lime is used. The claim is unsubstantiated.

"Analyses of the Benwood limestone would seem to indicate that some of the limestone beds are more desirable from a utilitarian point of view than others, the value of the limestone depending largely on the percentage of magnesium carbonate present (i. e. the value varies inversely with that percentage). The first of the following analyses was made from a sample taken in the railroad cut a quarter of a mile east of the Irwin station. The sample included all of the limestone beds in the basal 20 feet of the Benwood. The second analysis was made from a sample taken half a mile north of Herminie which included only the top three feet of limestone there exposed. The beds sampled were weathered to a light-buff color and were also rather soft. They were chosen in order to test a theory formed during the progress of several seasons' field work—the theory being that the proportion of magnesium carbonate in a limestone is indicated by the manner in which the limestone weathers. In general it seems true that pure limestones are brittle and just as hard where exposed to weathering as where they are covered by hundreds of feet of rock and soil. Also, the weathered surface of a pure limestone is usually a lighter shade of the same color as the fresh rock. A dolomitic limestone, however, will weather to a yellow or light-buff color and the outside inch or so of the limestone will be comparatively soft. Whereas the pointed end of a geolologic hammer will rebound sharply from the weathered surface of a pure limestone if it be struck, the hammer will rebound dully or perhaps not at all from the weathered surface of a dolomitic limestone. The amount of softening is, generally speaking, proportional to the percentage of magnesium carbonate in the rock (assuming approximately the same exposure to weathering agencies).

Analyses of Benwood limestone

Pittsburgh Testing Laboratory, analyst

After drying at 105°C:

	1	2
SiO_2	6.40	15.88
Al_2O_3	1.01	3.77
Fe_2O_3	1.43	2.77
TiO_2	trace	.30
$CaCO_3$	85.78	54.65
$MgCO_3$	2.34	21.38
Loss on ignition (other than CO_2)	?	1.00
Alkalies and undetermined	1.21	.45

"There are many good quarry sites available in the area in which the Benwood limestone outcrops, but due to the greater percentage of limestone in the member in the southern half of the quadrangle, quarry operations for other than very local use, would probably be more profitable there. Probably the best location for a limestone quarry in the entire quadrangle is the hill just east of the junction of the Southwest Division and the Pittsburgh Division of the Pennsylvania Railroad."

In the southern and southwestern portions of Westmoreland County the Benwood-Uniontown limestones are well developed and have been quarried in many places. They have been quarried for lime in scores of localities and at the time when small iron furnaces were in existence in the region these quarries furnished much fluxing stone. In some places sections of 60 to 80 feet consist almost entirely of limestone with very little interbedded shale but elsewhere the shaly phase is more prominent. In the region of Mt. Pleasant and Pleasant Unity these limestones have been quarried. Some quarries north of Mt. Pleasant have operated in a band of stone 12 to 15 feet thick in the lower part of the section and elsewhere a good band about 7 feet thick has been utilized. At Port Royal in South Huntingdon Township these limestones are about 65 feet thick and 55 feet along Youghiogheny Creek in Rostraver Township.

Along the highway just west of Sewickley Creek at Mill Grove there is an exposure of about 10 feet of limestone interbedded with shale that seems to be the Benwood. The limestone appears to be somewhat argillaceous but could be used for agricultural lime.

Waynesburg limestone. The Waynesburg limestone has not been recognized in many parts of Westmoreland County. In the Greensburg quadrangle Johnson describes its characteristics as follows: (11, p. 27).

"From 1 to 15 feet below the Little Waynesburg coal is a limestone which in other areas attains a thickness of over 25 feet, and which has been called the Waynesburg limestone. In this quadrangle it seldom is more than five feet thick. Few good exposures of it were seen and it is not believed to be persistent over large areas. It usually consists of two or three beds of fresh-water limestone separated by soft clay. The limestone beds vary in color from gray to yellow depending on the extent to which they are weathered. The following section illustrates about the maximum development of the Waynesburg limestone in this region.

Section ½ mile southeast of Herminie

	Ft.	*in.*
Shale, brown	3+	
Limestone, dark gray, shaly at top	1	
Clay-shale, dark	3	6
Limestone, light gray, massive	3	
Sandstone, thin, hard beds and brown shale	12+	"

In the southern part of the county in the vicinity of Pleasant Unity and Mt. Pleasant it is present with a thickness of 4 to 6 feet.

LIMESTONES OF THE WASHINGTON GROUP

Mount Morris limestone. The Mount Morris limestone has a limited distribution in the southwestern townships of Westmoreland County and in a few small patches about Mt. Pleasant and Pleasant Unity. Johnson gives the following descriptions (11, p. 21).

"It is never over six feet thick in this area, the average thickness probably being less than three feet. Where best developed it consists of three benches, a yellow, weathered limestone above and hard, gray limestone beds close beneath it. Although this limestone is not thick, it seems to be quite persistent and was found at practically every point where its horizon was exposed."

"Many years ago (11, p. 127) the Mount Morris limestone was quarried and burned at a point three-fourths of a mile south of Westmoreland City, North Huntingdon Township. Six feet of limestone is exposed in the old quarry. The same limestone is well exposed along the new concrete road which passes through Chambers, North Huntingdon Township. Near the top of the first hill northwest of Chambers a sample was cut from the limestone, the analysis of which follows.

Analysis of Mount Morris limestone

Pittsburgh Testing Laboratory, analyst

After drying at 105°C:	
SiO_2	10.12
Al_2O_3	1.63
Fe_2O_3	3.29
TiO_2	.20
$CaCO_3$	74.97
$MgCO_3$	7.13
Loss on ignition (other than CO_2)	2.07
Alkalies and undetermined	.59"

Colvin Run limestone. The distribution of the Colvin Run limestone is about the same as for the Mount Morris. Johnson describes it as follows (11, pp. 19-20):

"Shale and sandstone fill the interval between the Little Washington coal and the next named bed, the Colvin Run limestone. This interval averages about 20 feet. The Colvin Run limestone caps several of the hills in the trough of the Irwin syncline in the district one mile and a half to two miles southeast of Irwin. It undoubtedly must be present in some of the hills farther south but is poorly exposed. The limestone consists of several beds close together and attains a thickness of nine feet.

"The following section was made at a quarry a quarter of a mile south of B.M. 1033 on the Lincoln Highway east of Irwin.

Section of Colvin Run limestone

	Ft.	*in.*
Shale, carbonaceous	1	
Limestone	1	8
Clay with many limestone nodules	3	
Limestone, yellow	4	6
Clay-shale, greenish-gray	3	6
Clay-shale with limestone nodules	2	
Limestone, gray	2	
Clay, gray	1	
Limestone, ferruginous		6"

"The Colvin Run limestone (11, pp. 126-127) occurs only in the tops of some of the higher hills in the trough of the Irwin syncline. It has been quarried for many years by the farmers on whose properties it occurs and when burnt is highly regarded as a soil sweetener. It has also been used to a small extent for road metal. A sample of the limestone was obtained from a quarry a third of a mile south of B.M.

1033 on the Lincoln Highway (Philadelphia and Pittsburgh pike). The sample included a proportionate part of each bed of limestone, the section including 4 feet of yellow, weathered limestone and 27 inches of fresh, gray limestone. The analysis shows the Colvin Run is a dolomitic limestone and hence would be unsuitable for fluxing purposes or for manufacturing cement."

Analysis of Colvin Run limestone

Pittsburgh Testing Laboratory, analyst

After drying at 105°C;	
SiO_2	8.40
Al_2O_3	1.72
Fe_2O_3	3.00
TiO_2	trace
$CaCO_3$	74.53
$MgCO_3$	9.76
Loss on ignition (other than carbon dioxide)	.70
Alkalies and undetermined	1.89

Washington limestone. The tops of a few hills in South Huntingdon and Rostraver townships seem to have small remnants of the Washington limestone, most of which has been removed by erosion. It is of the same characteristics as shown in Washington and Fayette counties where this limestone assumes considerable economic importance.

QUARRY ACTIVITIES

It would be impracticable to describe all of the limestone quarries that have been worked in Westmoreland County in recent years in which the limestones of the Conemaugh and Monongahela formations have been utilized. A number of these were visited during the summer of 1929 and they are therefore briefly described. They are not described under the particular limestones simply because in several instances more time than was available would have been necessary in order to determine the exact horizon.

The Westmoreland Limestone Co. has within recent years worked a limestone quarry near Calumet. It has been referred to the Fishpot limestone. It is an interbedded series of limestones and shales as follows.

Section near Calumet

	Ft.	*In.*
Blue siliceous limestone altering to gray color	4	0
Limestone	1	0
Shale		1
Limestone	1	1
Shale		6
Limestone		8
Shale parting		
Light bluish-gray limestone altering to a chocolate dove color	8	0
Blue shaly limestone	1	5
Shale parting		
Dark blue limestone weathering to a dove color, breaking with smooth surface	1	4
Shale parting		
Limestone and shale partly concealed		

The interbedded shale was difficult to separate from the limestone and some of the limestone that, when fresh, seemed to be satisfactory for highway construction failed to pass the sodium sulphate soundness test. The State Highway Department sampled the quarry carefully and found that 9 out of 14 samples collected were unsatisfactory. Stone which lay exposed over winter also showed considerable disintegration.

There are several abandoned openings on the hillside just west of Mammoth in all of which fairly good limestones are interstratified with shale layers. Along the highway about 1¼ miles northwest of Kecksburg, Alonzo Fenton was working a small quarry of similar material for his own use.

In the vicinity of Mount Pleasant a number of small quarries have been operated at different times. The only one of any consequence in recent years is that of F. D. Barnhart and Sons. The section is as follows:

Section in Barnhart quarry, Mount Pleasant

	Ft.	*in.*
Overburden	**5**	**0**
Limestone dark blue in color somewhat ferruginous and slightly shaly toward base	**1**	**8**
Shale		**1½**
Dark blue limestone in five layers of approximately equal thickness	**4**	**11**

The quarry face is about 300 feet long. The stone is burned into lime and mainly hydrated although some is sold as lump lime. It is sold under guarantee of 65 per cent CaO and 3 per cent MgO with a fineness of 250 mesh. The screenings are used for agricultural purposes.

In the vicinity of Manito limestone fragments from the fields or shallow openings have furnished small amounts of limestone which have been piled up in the fields and burned for local farm use.

Half a mile northeast of Crabtree an outcropping ledge of stone close to the highway has furnished some stone for burning for agricultural use as well as another 22-inch ledge somewhat higher in the hill.

Near New Alexandria a number of farmers dig small amounts of stone which they burn for local use at irregular intervals. The stone quarried is about 44 inches thick.

Near Shieldsburg the Salem mine of the Keystone Coal and Coke Co. has occasionally quarried a 4-foot bed of Upper Pittsburgh limestone for lime burning. It is said to contain about 70 per cent $CaCO_3$.

In the vicinity of Greensburg a number of small quarries have been opened at different times to obtain stone for burning or for use on the township roads. J. W. Steel has worked a little stone near Hannastown consisting of a 3-foot bed of massive blue to dove-colored limestone above a 4-foot thickness of thin laminated beds, the two separated by 3 to 4 inches of clay.

A few miles northeast of Ligonier a number of small quarries have been worked at different times. The most important one recently is

that of the Naugle Lime Co. located on the east side of Hannas Run about 3 miles northeast of Ligonier. The quarry section is as follows:

Section in Naugle Quarry, 3 miles northeast of Ligonier

	Ft	*in.*
Overburden	2	6
Bluish gray limestone	1	6
Blue limestone	5	6
Clay		

The company operates one steel-jacketed kiln. The lime is sold for agricultural use.

CALCAREOUS MARL

In a brief report on some calcareous marl deposits of the State by J. B. R. Dickey, published as Bulletin 76 of this Survey, the following brief description is given:

"A sample of marl from the farm of E. E. Myers, North Alexander, was analyzed several years ago and showed 52 per cent total carbonate. The writer has not seen this deposit."

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WYOMING COUNTY

Sandstones and shales constitute practically the entire geologic section of rocks outcropping in Wyoming County. The Catskill and Chemung series are well developed and although they consist almost entirely of sandstones and shales, here and there several thin beds, 2 to 6 feet thick, of impure limestones have been noted. Some of these beds are greatly brecciated. So far as known they have never been utilized for any purposes for which limestones are of especial value. The county may be said to be without limestones of economic importance.

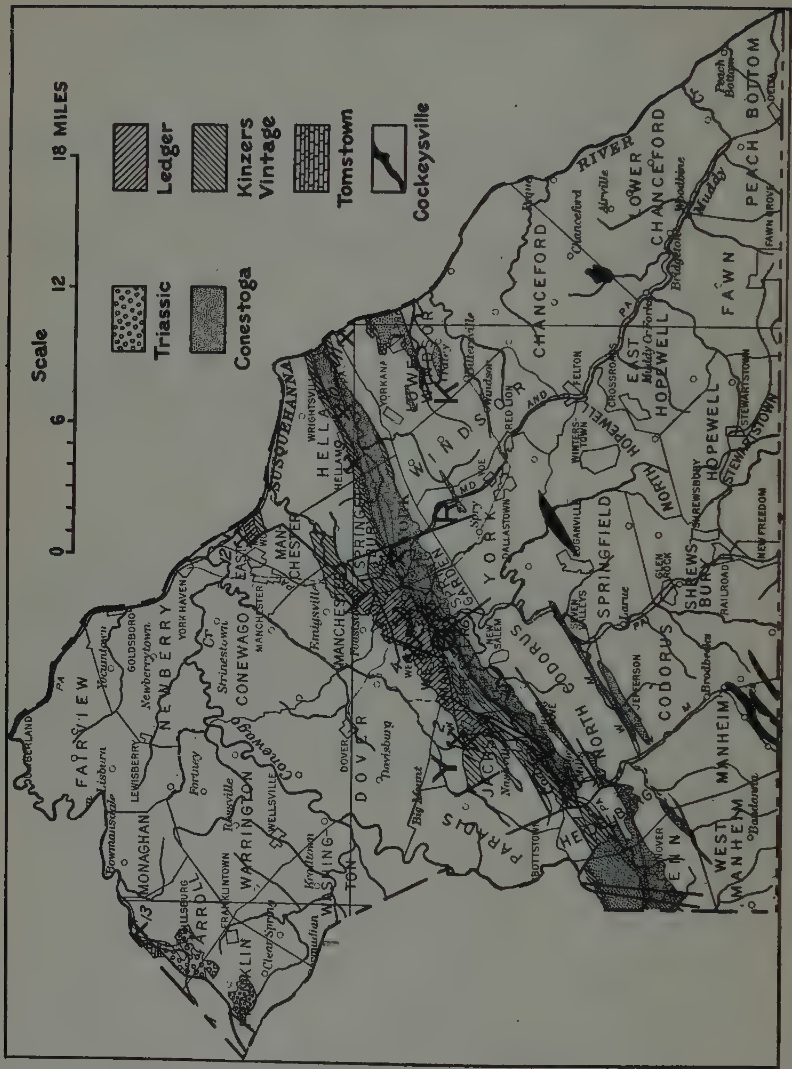

Fig. 34. Limestone areas in York County.

1. Thomasville Stone and Lime Co.
2. J. E. Baker Co.
3. Medusa Portland Cement Co.
4. J. E. Baker Co.
5. York Stone and Supply Co.
6. Universal Gypsum and Lime Co.
7. Eli Z. Zinn
8. A. M. Hake Co.
9. York Valley Lime and Stone Co.
10. Wrightsville Stone and Lime Co.
11. Susquehanna Stone Co.
12. J. E. Baker Co.
13. Williams Grove quarry.

YORK COUNTY

York County has long been one of the important limestone producing counties of Pennsylvania. It contains a variety of limestones suitable for various purposes and in several places there are large quarries that are still highly productive. Quarrying is favored by good transportation facilities for shipping throughout the limestone sections and also a rather large local demand for stone.

The limestones of the county occur in three different bands. The most northerly one covers a small area near New Holland and represents the western end of an extensive band that extends across Susquehanna River from Lancaster County. There is only one quarry in this area but it is large.

The main band crosses the river at Wrightsville and continues in a southwesterly course entirely across York County and to Littlestown, Adams County. This more extensive band of limestones underlies and is responsible for the formation of York Valley in which are located the principal towns and industries of York and Adams counties. The valley averages about 1½ miles wide except in the vicinity of York where it is about 5 miles wide. The southern boundary is a fairly regular line with few indentations but the northern one is irregular. In the vicinity of York one off-shoot of the main valley extends northwestward to Emigsville and another extends westward a few miles beyond Thomasville. Both of these branch valleys owe their existence to folding and faulting by which limestone is brought to the surface.

On the north side of the limestone valley there are exposed either the underlying Chickies quartzite or the much more recent overlapping red shale and sandstone of Triassic age. The strata bounding the valley on the south are principally slate or schist, probably in the main of Ordovician age.

The third area, like the first, represents the continuation of a much more extensive area that crosses Susquehanna River from Lancaster County and continues a short distance beyond East Prospect.

Until recently the limestones were believed to belong entirely to the Cambrian system, as Walcott and others had collected Cambrian fossils from various places within the valley. Stose and Jonas[7] now refer the limestone conglomerate and associated strata, so extensively developed in York County, to the Conestoga formation and state that they have found in them, east of York, some brachiopods and crinoid stems and plates that are regarded as of Chazy age. Their revised columnar section is given on a previous page under the discussion of the Lancaster County limestones. The formations best developed in York County are the Vintage dolomite, Kinzers formation and Ledger dolomite of Cambrian age and the Conestoga limestone of the Ordovician.

CAMBRO-ORDOVICIAN LIMESTONES

The structure of the York County limestones is very complex, as is true of all of the limestone areas of southeastern Pennsylvania, and much detailed work is necessary before it is possible to do more than outline the most general features. In almost every quarry or extensive natural exposure there is evidence of intricate folding and fault-

ing. The mantle of residual clay soil that covers the limestone almost everywhere except along erosion channels and artificial excavations, prevents the acquisition of data that might make it possible accurately to determine the structures. To determine the structure of a limestone property it is necessary to prospect either by extensive drilling or by digging trenches or pits.

It seems that nearly all the folds are closely compressed and that the strata have a more or less prevailing steep dip to the southeast although there are many exceptions to this generalization.

The numerous varieties of limestone are practically all crystalline and many of them have been converted into beautiful medium coarse-grained marbles. The degree of marmarization depends partly upon the amount of compression that the strata have undergone but more upon the original physical and chemical composition of the rocks. The massively bedded strata are much more crystalline than the thinly bedded ones and the purer limestones and dolomites are likewise more highly crystalline than are the argillaceous or arenaceous varieties.

Many minerals characteristic of metamorphic calcareous rocks are present. Numerous vein minerals are also found in small quantity, most of them probably brought in by the heated circulating waters during the process of metamorphism. Jandorf (4, 106-112) lists the following minerals that have been found in these limestones:

Graphite	Fluorite	Ankerite	Serpentine
Galena	Quartz	Siderite	Talc
Sphalerite	Hematite	Aragonite	Nitro-calcite
Chalcopyrite	Limonite	Malachite	Barite
Pyrite	Calcite	Asbestos	Gypsum
Marcasite	Dolomite	Chlorite	

Conglomerates. Almost every quarry of considerable size exposes a number of layers of stone possessing different physical as well as chemical characters. One of the most interesting phases is the conglomerate or breccia variety of the Conestoga formation that is well developed in the vicinity of York and extends eastward to Wrightsville and westward to Thomasville. This has been called "intra-formational conglomerate" and also "edgewise conglomerate." The latter term is appropriate only where the fragments are thin and are not parallel to the bedding planes. In some places the fragments and the cementing matrix are so nearly the same color and so similar in all other respects that a freshly broken piece of rock scarcely reveals the conglomeratic character but on exposure to the weather the matrix is dissolved more readily and the fragmental origin of the rock is strikingly exhibited. At the quarry of the York Valley Lime and Stone Co. near Hellam Station beautiful examples of this can be seen. In certain places the fragments are lighter or darker in color than the matrix and the fragmental character can be readily determined. The best examples of this were observed in the quarries of the Universal Gypsum and Lime Co., southwest of York. The stone is there termed "calico rock" and two different types occur. One, known as "light calico," has angular and irregular fragments of a dull gray color enclosed by a matrix of white stone, with both fragments and matrix well crystallized. The other variety, called "dark calico," contains dark bluish gray fragments in a muddy gray cement. In places this matrix contains an appreciable quantity of pyrite. The fragments of this con-

glomerate are of various sizes up to 3 feet in diameter. In some places the fragments are fairly uniform in size but, in general, large and small pieces are present in the same bed. Some are rounded as though they have been worn by being rolled but most are decidedly angular and seem to indicate ice transportation as suggested by Walcott. No explanation that has thus far been offered for conglomerates of this kind seems to account satisfactorily for the formation of these York Valley conglomerates.

Variations in character. Massive and thin beds of uniform color—white, gray and dark bluish gray to almost black—are also present, interbedded with the conglomerates. In portions of some quarries the rock is so uniform that it is difficult to determine the bedding planes.

Thin shaly layers of little value for any purpose are present in some quarries and materially add to the difficulties and expense of operation.

In places an especially soluble layer has become porous or cavernous near the surface. The openings have a tendency to fill with clay washed down from the surface and are then objectionable. A 5-foot bed of this kind at the quarry of the Thomasville Stone and Lime Co. contains so much clay that it is difficult to keep the good stone clean.

Oolitic limestones are not abundant in the region but are found occasionally. The best example noted was at the quarry of the Thomasville Stone and Lime Co.

The York Valley contains a large quantity of unusually fine stone. It has yielded a great deal of low silica dolomite and low silica and low magnesiam limestone so that much of the raw stone and the lime formed from it have been in demand for fluxes and for various chemical uses. In addition there are many high silica limestones and dolomites that are better than the low silica varieties for crushed stone and ballast.

Some of the quarry men have been fortunate in finding sufficiently large bodies of high grade stone of fairly uniform composition so that they have little difficulty in meeting the demands of their customers. Generally, however, due to complexity of structure and variations in chemical composition of the different beds, and even within the same bed, the operators must exert unusual care in working their quarries in order to obtain a uniform product. The quarries worked for chemical limestone or lime must carefully avoid the spots where the stone is high in silica, alumina and pyrite, whereas the quarries furnishing crushed stone must waste the shaly layers sometimes encountered.

For these reasons it is always well to sink a number of test drill holes before opening any quarry in the region unless the natural exposures are unusually good.

No better example of variations in the stone can be given than the data obtained on the farm of S. Forry Laucks, 2 miles north of York where 10 core drill holes were put down to depths of 125 to 263 feet. The rock at that point as exposed in two small abandoned quarries is metamorphosed to such an extent that the bedding planes are indistinct. Except in a very general way and for the holes relatively close together it was not found possible to correlate the beds by either chemical or physical characters.

Sections and analyses of limestone from Laucks farm 2 miles north of York

	Feet	$CaCO_3$	$MgCO_3$	Al_2O_3 Fe_2O_3	SiO_2	P for entire hole
Hole No. 1—261 feet						
A. White dense crystalline stone	42	97.89	1.66	0.32	0.20	---------
B. Grayish blue stone	4	98.37	1.47	0.20	0.04	---------
C. Same as A	33	96.81	2.89	0.20	0.12	---------
D. Approximately dolomite	1	59.20	40.25	0.44	0.11	---------
E. White crystalline stone	83	96.87	2.76	0.15	0.25	---------
F. Light blue stone	38	95.72	3.97	0.20	0.17	---------
G. Light blue stone with pink discolorations	21	93.12	6.52	0.24	0.18	---------
H. Blue stone slightly darker than G	68	91.92	6.30	0.55	1.24	---------
I. Dark blue stone	22	83.82	14.24	0.63	1.39	---------
J. Very dark blue stone, rather soft and graphitic	19	75.44	21.87	0.93	1.84	0.004
Hole No. 2—217 feet						
Overburden 2 feet						
A. White crystalline stone	18	97.95	1.83	0.06	0.11	---------
B. Dense crystalline gray stone 2 feet						
Gray stone 0′8″						
Gray stone 0′6″						
Gray stone 1′10″	5	62.45	36.79	0.38	0.34	---------
C. White stone 11′						
White stone 1′						
Dense white crystalline stone 53′ with pinkish tints in spots and turning grayish towards lower 20′	65	96.89	2.83	0.31	0.17	---------
D. Dense grayish white stone	71	96.14	3.43	0.27	0.12	---------
E. Darker gray stone	44	85.76	12.46	0.50	1.30	---------
F. Very dark blue stone graphitic	12	76.16	21.79	0.66	1.50	0.005
Hole No. 3—263 feet						
Overburden 2 feet						
A. White crystalline stone with small blue inclusions	128	97.40	2.55	0.14	0.11	---------
B. Gray hard stone 4′						
Gray stone 3′	7	73.32	25.48	0.48	0.66	---------
C. White stone 3′						
White stone 10′	13	93.44	6.02	0.25	0.36	---------
D. Rather hard gray stone 57′						
Streaked with blue 4′	61	62.51	34.54	0.73	2.33	---------
E. Dense blue stone 25′						
Dense blue stone 27′	52	91.94	6.77	0.43	0.90	0.0045
Hole No. 4—150 feet						
Overburden 7 feet						
A. Dense white crystalline stone	79	96.55	3.06	0.19	0.22	---------
B. Blue stone	16	97.00	2.64	0.13	0.17	---------
C. Gray crystalline stone, dense but weathered in spots	48	73.11	25.90	0.76	0.11	0.0025
Hole No. 5—125 feet						
Overburden 12 feet						
A. Dense white crystalline stone with pinkish tint	44	95.91	3.68	0.15	0.23	---------
B. Pinkish gray stone with streaks of dense white crystalline stone	30	62.67	36.51	0.56	0.13	---------
C. Dense gray stone	20	94.42	4.99	0.19	0.25	0.003
D. Siliceous, poor looking stone 19 feet	---------	---------	---------	---------	---------	---------
Hole No. 6—144 feet						
Overburden 9 feet						
A. White stone	6	97.54	2.05	0.16	0.20	---------
B. Gray crystalline stone	29	75.78	23.78	0.27	0.13	---------
C. Blue stone getting darker with depth	65	92.80	5.89	0.44	0.92	---------
D. Dark blue stone	5	79.40	18.48	0.69	1.36	0.006

	Feet	$CaCO_3$	$MgCO_3$	Al_2O_3 Fe_2O_3	SiO_2	P for entire hole
Hole No. 7—106 feet Overburden 10 feet						
A. Dark blue graphitic stone slightly dolomitic	96	92.28	5.93	0.43	1.42	0.012
Hole No. 8-247 feet						
A. Dolomitic stone in spots	17	86.95	10.95	0.44	1.66	----------
B. Dolomite 3′ Dolomite 0′6″	3½	55.66	43.03	0.64	0.74	----------
C. White stone 4′ White stone 70′6″	74½	96.04	2.90	0.24	0.78	----------
D. White stone siliceous in spots	52	88.43	3.22	0.20	8.22	----------
E. Dolomite	4	57.69	40.99	0.44	0.72	----------
F. Light blue mottled stone	33	94.30	3.52	0.14	1.90	----------
G. Dolomite	18	55.70	43.30	0.43	0.58	----------
H. Rather poor looking dolomite	45	88.44	9.29	0.59	1.87	0.007
Hole No. 9—227 feet Overburden 4 feet						
A. White crystalline stone	40	97.81	1.86	0.12	0.28	----------
B. Dolomite	6	63.84	33.96	0.71	1.48	----------
C. White stone with pinkish discoloration	65	97.96	1.75	0.10	0.27	----------
D. Dolomite	1	61.61	37.47	0.26	0.49	----------
E. Dense white stone with grayish streaks	45	97.24	2.31	0.13	0.40	----------
F. Grayish limestone	56	95.53	3.14	0.15	1.10	----------
G. Dolomite weathered	10	57.92	41.48	0.33	0.27	0.003
Hole No. 10—147 feet Overburden 4 feet						
A. Hard dense dolomite	143	55.01	43.42	1.09	0.34	0.010

Uses. The limestones of York County have long been quarried and the limestone industry has passed through about the same stages described in the discussion of other regions. The earliest uses were for building purposes and for agricultural lime and numerous small openings were made to supply local users. From 1850 to about 1885 the numerous limonite iron ore mines of the limestone valley and adjoining regions and some magnetite mines in the older crystalline rocks to the south were worked and the ores reduced in the near-by region. Many limestone quarries were therefore opened to supply stone for flux. With the closing down of all these iron mines, the increase in cost of labor, and the improvement in railroad transportation, the small quarries were abandoned and large quarries were opened near the railroads and in localities where the quality of the stone is superior. These have been extensively worked for lime. The latest extensive use has been for crushed stone for roads and for concrete.

The limestones of York County are not particularly well adapted for construction purposes, although local stone has been used for a number of buildings and still more has been used for foundations. The joint planes are numerous and irregular so that in most places it is difficult to get out building blocks without undue waste. These joint planes are mainly due to the great compression which the strata have undergone.

Dressed marble, so far as known, has never been taken from the York Valley, notwithstanding the fact that in several places north and west of York there are some beautiful varieties. Some of the

cores obtained in diamond drilling on the farm of S. Forry Laucks 2 miles north of York, have been polished and are unusually attractive. There is some pure white stone, but most is handsomely mottled, particularly the conglomerate layers described on a preceding page. There are the light varieties and the darker shades and one gray and white with pink bands and blotches. Undoubtedly the marble would find a market for interior decoration. It would have to be quarried with channeling machines as the stone breaks too irregularly in blasting. On account of joints there might be a large amount of waste although at lower levels the joints would probably be less numerous. The high grade character of the stone as shown by the analyses on a preceding page, would permit the utilization of the refuse for lime, flux, or other uses.

High grade chemical lime is made at several places, most notably at the Thomasville quarries, and those located west and southwest of York.

White and ordinary Portland cement are made 1 mile west of York by the Medusa Portland Cement Co. Formerly a limestone quarried adjacent to the plant was used. Later the stone was obtained from the Thomasville quarries, but at present it is being quarried about 1½ miles northwest of West York. The white clay mixed with the limestone is obtained from Cumberland and Huntingdon counties.

Fluxing stone was once quarried extensively and many of the quarries primarily worked for lime have stone that would be highly desirable for flux.

The demand for crushed stone has been so great during the past few years that many quarries have been worked entirely for this product. These are mainly near York and Wrightsville.

Space will not permit a separate description of each quarry but a few districts are worthy of special attention. In the 1910-1912 Report of the Topographic and Geological Survey Commission of Pennsylvania, M. L. Jandorf has given a somewhat detailed description of 16 quarries between Wrightsville and Hanover.

DESCRIPTION BY DISTRICTS

Thomasville Area. The Thomasville Stone and Lime Co. and J. E. Baker Co. have long quarried high grade limestone in the vicinity of Thomasville. The former company has the largest quarry in York County, covering several acres. The stone is mainly a fine-grained, soft, crystalline, white to gray marble of excellent quality. In addition, some of the marble of good grade is dark blue in color, some banded gray to dark blue, and some distinctly brecciated, presenting a blotched appearance. There are some dolomitic layers, especially underlying the good stone. The strata are approximately horizontal throughout most of the quarry, an unusual feature for this region, but in two places small anticlinal folds bring the underlying dolomite above the quarry floor. One of these anticlines rises about 10 feet above the floor. This is a disadvantage in quarrying as the company uses no rock high in magnesia. On the northwest side of the large quarry, a block of Triassic shale and limestone conglomerate has been faulted down to the level of the good stone and thus interfering with the extension of the quarry in that direction. The large quarry is from 50 to 60 feet high.

When the plant was revisited in 1930, a new quarry had been opened to the south of the lime kilns but it was small. The stone obtained from the new quarry is similar to that from the older and larger opening.

The plant is well equipped with steam shovels, crushers, screens, kilns, hydrating machines, etc. The product of the quarries is used for almost all the purposes for which there is a demand for high calcium, low silica and low magnesian limestone. The company has long burned a large part of the stone quarried. There are 14 flame kilns in operation. In addition much is sold for fluxing purposes, and for manufacture of Portland cement. Some is crushed to the size required by glass manufacturers and some has been pulverized for fertilizing purposes.

Analyses of limestones, Thomasville Stone and Lime Co.

$CaCO_3$	88.51	36.90	98.27	99.25	99.10	98.23
$MgCO_3$	10.87	42.30	1.07	0.14	2.24	1.14
Al_2O_3	0.06	0.04	0.10	0.10 }		
Fe_2O_3	0.20	0.44	0.05	0.05 }	2.40	0.17
SiO_2	0.27	0.30	0.35	0.19	0.40	0.25
Moisture			0.18	0.18	0.08	0.08

The above analyses show different types of stone represented in the quarry, ranging from those low to high in magnesia, but all low in silica.

The annual capacity is about 27,000 tons of lime, 32,000 tons of pulverized limestone, 180,000 tons of ballast stone and screenings, 137,000 tons of fluxing stone, and 155,000 tons of open hearth furnace stone.

The J. E. Baker Co. also operates at Thomasville with two quarries. The larger and older one is just across the road to the east of the plant of the Thomasville Stone and Lime Co. In the larger quarry, several different grades of stone are exposed, including white marble of high $CaCO_3$ content, mottled brecciated or conglomeratic marble of good quality, and some high magnesian stone. The best grades are burned for lime at the plant where there are 8 steel flame kilns or hauled to the crushing plant at West York to be pulverized for whiting. The magnesian and siliceous stones are crushed for road metal and concrete. The strata dip to the north at varying angles. The quarry is about 85 feet deep and relatively narrow, because much widening could only be done by quarrying considerable dolomitic stone which is less desirable.

Analysis of limestone in J. E. Baker quarry at Thomasville

$CaCO_3$	98.20
$MgCO_3$	1.53
$Fe_2O_3 + Al_2O_3$	0.12
SiO_2	0.15

Across the Lincoln Highway to the north, the same company was opening a new quarry in the summer of 1930. The opening was small but exposed some high grade stone as well as some of fairly low grade.

York Area. Limestone quarries have long been worked in the vicinity of York and have yielded stone suitable for practically all purposes.

About 1½ miles west of West York the Medusa Portland Cement Co. opened a quarry in 1922 to supply stone for their cement plant located in the southwestern portion of West York. Previous to the opening of this quarry, the company had purchased its limestone, first to manufacture white cement and later the ordinary gray Portland cement as well. When visited in 1930, the quarry showed beds dipping at various angles up to 60° south. There are a number of faults in the quarry, which have displaced the beds and introduced problems of quarrying. Much core drilling has been done to determine the type of stone in advance of drilling for blasting. Beds of high lime content are interbedded with layers fairly high in magnesia, and faulting has resulted in the striking of poor stone where good material was expected, and vice versa. Nevertheless, with care a great deal of stone well suited for Portland cement can be obtained. The surficial clay overlying the limestone is also sent to the cement plant for adding to the limestone to produce the proper mix. The plant produces annually 600,000 barrels of gray cement and 500,000 Portland barrels of white Portland cement.

The J. E. Baker Company's quarry at this place is located just west of the Medusa quarry. Here also there are both high and low magnesian strata. The quarry yields high grade limestone which is pulverized for agricultural use or used as a filler for asphalt or for whiting. The stone is pulverized to different degrees of fineness for different uses as per specifications. Most is ground to pass through a 100-mesh screen. A Raymond mill does the fine crushing. Some magnesian stone is interbedded with the low magnesian strata so it is necessary to select carefully when chemical requirements are strict.

The York Stone and Supply Company is working a quarry for crushed stone in the side of a hill about three-fourths mile north of York. The capacity of the plant is about 450 tons per day. The older quarry had a face about 90 feet high, but at present a new cut about 30 feet is being made in the bottom of the former quarry. The strata are fairly regular, dipping gently westward. Although numerous faults are visible, none shows a displacement of more than a few feet.

At the top of the quarry there is a band of dark blue siliceous and magnesian limestones in which some layers are decidedly sandy. Beneath is a thick band of gray to buff to pinkish fine-grained dolomite. This overlies a gnarly hard siliceous and magnesian limestone which passes downward into a rock more uniform in texture, consisting of dense blue siliceous dolomite much shattered and containing numerous calcite veins. Some fluorite and quartz are associated with the calcite. All of the rock in the quarry is highly magnesian, very hard, and well suited for crushed stone. At times, blocks of stone for buildings have been taken out but the demand for such material is small.

About three-fourths mile south of West York is the large quarry of the Universal Gypsum and Lime Company (formerly the Palmer Lime and Cement Company). The quarry furnishes several different kinds of stone of which four are more or less regular. There are: (1) a very white granular rock, which in places contains a few small pink blotches; (2) a very soft bluish banded rock; (3) a light colored "calico" rock, angular white fragments in a grayish matrix; (this contains 12 to 15 per cent $MgCO_3$.) (4) a dark colored "calico" rock,

black fragments in a dark grayish matrix which runs high in silica and magnesia.

The first two varieties are burned for chemical lime or agricultural lime or pulverized raw for whiting. For this last purpose, it is ground sufficiently fine for 98 per cent to pass through a 200-mesh screen. These two varieties of stone contain from 98 to 99 per cent $CaCO_3$, 0.56 to 1.09 $MgCO_3$, 0.08 to 0.22, Al_2O_3 and Fe_2O_3, and 0.06 to 0.28 SiO_2.

The other two varieties are used for crushed stone. A typical analysis is as follows: $CaCO_3$, 82.10; $MgCO_3$, 17.18; Al_2O_3 and Fe_2O_3, 0.60; SiO_2, 0.12.

In order to get more of the high grade stone, the ledges which are almost flat but with a few rolls and small faults have been followed into the hills beneath the lime plant. In 1930, the underground workings had been extended a distance of about 350 feet with rooms 40 feet wide. The rock is so massive that no timbering is required although one rock fall was reported. The work was started with a 10-foot slice, but later another 10-foot slice was made in the roof. The best stone is picked carefully for whiting, somewhat less carefully for chemical lime, and still less for agricultural lime. At times, 65 per cent of the stone is suitable for whiting. The two varieties of good stone aggregate 40 to 50 feet in thickness. Some of the stone in the quarry, particularly the ''calico'' stone, might make beautiful decorative stone for interior building use. It is highly ornamental when polished.

Eli Z. Zinn is working a rather large quarry for crushed rock in the south part of West York. The face of the quarry is about 100 feet high. A beautiful anticlinal fold is to be seen in the quarry face. A considerable part of the quarry consists of fairly high grade, low magnesian stone which is pulverized. The balance is more siliceous and dolomitic and is crushed for ballast. The annual capacity of the plant is given as 58,000 tons of crushed stone.

The A. M. Hake Company operates a quarry in the northeast part of York. The opening is about 300 feet in diameter and 40 to 50 feet deep. The beds are massive and consist mainly of siliceous and magnesian stone although there are some beds of fairly soft, high-calcium stone. The beds dip to the southeast at varying angles but probably average about 25°. Faults are rather numerous but apparently the displacement is everywhere small. Some fine calcite crystals were obtained from an open cavity which was coated with them. The entire production of the quarry is crushed stone used for highways and in general concrete work. The daily capacity is about 300 tons.

Hellam Station Area. Several quarries have been worked in the vicinity of Hellam Station. The principal one of those worked in recent years is on the farm of Walter F. Myers, leased by the York Valley Lime and Stone Co., a short distance west of Hellam Station. There are 12 flame kilns on the property but in recent years little lime has been burned. Nearly all has been crushed for highway and concrete use. The daily capacity of crushed stone is about 600 tons. The quarry contains mainly magnesian stone not suitable for high grade lime but there are two bands of high calcium; one of them 30 feet in thickness was formerly worked for stone to be burned. There is also a 20-foot layer of low-silica dolomite interbedded with the other strata.

One of the bands of high grade calcium stone was worked as close to the road as safe and then a tunnel was run under the highway to obtain some good stone in the field to the south. In this quarry one can see beautiful examples of limestone conglomerate.

At Stoner's Station stone has been quarried for lime in a small way and efforts have been made by the Wrightsville Stone and Lime Co. to expand the operations.

Section in face of quarry at Stoner's Station

	Feet
Limestone conglomerate	11
Thin to thick beds of limestone	25
Shaly limestone	2
Limestone breccia	8
Shaly limestone	2
Extremely coarse limestone conglomerate	12
Shaly layer	3
Limestone conglomerate	8
Shaly conglomerate exposed in bottom	

Wrightsville Area. Two old quarries at Wrightsville have furnished a large amount of stone for lime in the past. One of these, belonging to the Beard Lime Company, was closed a few years ago when an extensive landslide occurred, and the other one owned by the Steacy-Wilton Company, was later closed when the operations were extended almost to the property lines. When visited in 1921, it was being worked for crushed stone and supplying about 100 tons per day. The dip and strike were determined at a place that seemed to represent a fair average of the prevailing inclinations and found to be: strike N.80°W, dip 55°SW. There are several varieties of rock in the quarry, some of which are shaly and of little use. A layer of impure limestone about 4 feet thick has been quarried for building purposes. Conglomerate layers are common throughout the quarry. In some of them the individual fragments are 10 to 12 inches in diameter.

In 1929, the Susquehanna Stone Company opened an old quarry close to the river road just south of Wrightsville. The stone is a massive dolomite outcropping in the side of the hill. The stone is excellent for crushed stone for which it is worked but the overburden of clay is heavy. The capacity of the crusher is about 300 tons per day.

New Holland (Saginaw) Area. Just north of New Holland (Saginaw P. O.) there is a triangular area of limestone in which the J. E. Baker Company has long worked a large quarry. It is said to have been opened in 1903. This quarry at one time supplied a great deal of limestone for railroad ballast. It is now yielding two products, high magnesian stone low in silica for fluxing purposes, and high silica magnesian rock for crushed stone. The two products are quarried separately and hauled up separate inclines to separate crushing plants. The quarry level for the fluxing dolomite is being advanced along the strike of the band which is about 100 feet thick. It is overlain and underlain by siliceous beds. The underlying siliceous stone is being worked at a lower level. It can be obtained in large quantities as there are 37 loading tracks. From the quarry northward to the contact of the overlying Triassic strata there are numerous exposures of dolomite. Some layers are said to be low in silica.

Analysis of limestone, J. E. Baker Co., Saginaw

$CaCO_3$	87.08
$MgCO_3$	11.13
Fe_2O_3, Al_2O_3	.62
SiO_2	1.17

Dillsburg Area. Yellow Breeches Creek forms most of the northern boundary of York County. In its various meanders, it shifts from the Triassic belt to the limestone area forming the floor of the Cumberland Valley, so that some limestone in that section is included within York County. The only place where much limestone has been quarried in this part of the county is in the extreme northwestern corner about 2½ miles north of Dillsburg where Williams Grove quarry is located. The quarry is said to have been opened about 36 years ago. For about 9 years, it was worked mainly to supply ballast for the Pennsylvania Railroad. The stone from this quarry has also been widely used for State highways. It yields a fine grade of crushed stone as the rock is a dense and tough blue dolomite. It breaks into irregular angular fragments. When visited in 1930 the working face was about 500 feet long and 85 to 100 feet high. The quarry is opened in the side of a hill with very favorable quarrying conditions. A few clay filled joints and solution cavities extend to the quarry floor. The clay overburden is heavy. A few small caves containing stalactites and stalagmites have been encountered. This quarry has been extended nearly to the boundary of the property owned by the company.

TRIASSIC LIMESTONES

In addition to these Paleozoic limestones, some limestone conglomerates of Triassic age in the Dillsburg region were worked on a small scale many years ago. Frazer (3, p. 225) describes a quarry in operation in 1875 as follows:

"John Kuntz's limestone quarry is situated about 1 mile N.W. of Dillsburg. The quarry is in a coarse conglomerate resembling the Potomac Marble. The lime is said to be equal as a fertilizer to that of the Cumberland Valley. It sells in the neighborhood for nine cents per bushel at the kiln. Mr. Kuntz pays $20.00 per thousand bushels for the right of quarrying this rock. The admixture of sandstone does not appear to interfere with the utility of the conglomerate as a top dressing.

"Two dips taken at the east end of the quarry gave, respectively, S. 45°W.-24°, and S. 10°E.-40°.

"This belt of conglomerate limestone resembles that of the Auroral limestone in being honeycombed into caverns below water level. A stream flows into a hollow at this quarry and disappears after the manner of similar streams at various points of the great valley."

In Report M3 (pp. 79-80) the following analyses of this same type of stone from quarries, just north of Dillsburg, are given:

Analyses of Potomac marble from Welty's quarries, near Dillsburg

CaO	44.950	44.220	47.000	42.940	43.920
MgO	5.275	6.403	3.845	3.045	2.929
FeO	1.179	.864	.585	1.098	2.304
MnO	trace	trace	trace	trace	trace
Al_2O_3	2.460	2.320	1.690	2.680	5.090
S	.004	.003	.004	.003	.005
P	.011	.012	.003	.013	.031
CO_2	31.040	34.030	34.985	30.072	17.020
H_2O	1.460	1.150	1.270	1.160	1.720
Insoluble residue	14.010	10.890	10.460	18.580	27.010
Total	100.389	99.892	99.842	99.591	100.029

The ignited insoluble residues contain:

SiO_2	11.603	8.766	7.710	13.144	25.320
Fe_2O_3	.039	.148	.211	.126	.113
Al_2O_3	.236	.126	.231	.524	.205
CaO	.838	.634	1.238	2.560	.433
MgO	.666	.465	.819	1.777	.301

"Welty's quarries, on the Dillsburg branch of the C.V.R.R. about a third of a mile north of the depot at Dillsburg. Mesozoic limestone.

"Brecciated; rather hard and tough, with irregular fracture; color, generally greenish grey. Portions of the mass consist of a white saccharoidal limestone. Some of the specimens show beautiful dendritic impressions."

In Report M (p. 77) another analysis of this stone from near the same locality is given as follows:

"$CaCO_3$ 73.180, $MgCO_3$ 4.370, Fe .520, Insoluble residue 21.500.

"In bottom of M'William's Slope, one mile northeast from Dillsburg.

"Limestone conglomerate, crystalline; color greenish grey."

Prof. M. H. Bissell* furnishes the following brief descriptions of a few localities in York County:

"Excellent exposures of this conglomerate may be seen in the steep bank of Yellow Breeches Creek some two miles north of Lisburn, and in the Pennsylvania Railroad cuts on the west bank of the Susquehanna River two to three miles southeast of New Cumberland.

"In the first of the above-mentioned localities a cliff ten to twenty feet or more in height is made up of great masses of conglomerate with interbedded strata of sandstone and shale. Some of the conglomerate is exceedingly coarse, containing bowlders two feet in diameter, with which are mixed, without any suggestion of sorting, fragments of heterogeneous sizes down to small pebbles. The material is partly limestone, partly quartzite and red sandstone. Some of it is rounded and some quite angular. Although thick beds of such heterogeneous material show no sign of sorting, in places they overlie beds of sandstone with almost no conglomerate, and even thin strata of shale are interbedded with the coarsest conglomerate.

"South of the Paleozoic-Triassic contact on the west bank of the Susquehanna, below Marsh Run, the breccia-like character of the Potomac marble is more strikingly shown. Here the rock is a limestone breccia containing angular fragments of all sizes up to about one foot in diameter (Plate XIV A). Many of the fragments are much flattened, but are not arranged with their long axes parallel. Although limestone is the predominating material, white and yellow quartzite, red sandstone and shale, and schist are found as fragments. Near the signal tower in the railroad cut, a bed of such breccia or conglomerate ten feet thick is overlain and underlain by red sandstone."

CALCAREOUS MARL

The Geological Map of York County, published by the Second Geological Survey of Pennsylvania, shows an area of marl in the flat alluvial valley of Dogwood Run extending from Dillsburg northward slightly more than a mile. No description is available and the deposit has not been investigated by the writer.

*Personal communication to the author.

Additional analyses of York County limestones

	1	2	3	4	5	6	7	8	9
$CaCO_3$	87.39	88.78	53.02	67.36	53.09	54.25	60.67	80.64	77.16
$MgCO_3$	8.11	9.95	37.80	11.01	40.09	41.84	22.86	14.00	18.27
SiO_2	3.60	0.80	1.10	14.87	4.36	2.00	12.88	4.27	3.48
Al_2O_3	0.25	trace	0.73	4.09	1.57	1.00	2.29	0.22	0.35
Fe_2O_3	0.57	0.35	7.17	1.98	0.88	7.75	1.28	0.85	0.85
S	trace	trace	0.00	0.00	0.00	trace	0.004	0.02	0.015
P	0.017	0.012	0.090	0.097	0.100	0.115	0.034	0.018	0.028

1. Abandoned quarry on farm of Wm. Keffer, 1½ miles north of Hanover; average of 2 samples.
2. Small quarry on farm of Samuel Witmer, 1¼ miles north of Hanover.
3. Outcrop along railroad at Jacob's Mill, 3 miles northeast of Hanover.
4. 2 small quarries on farm of J. J. Hershey along R. R. 1 mile southwest of Menges Mills. Average of 2 samples.
5. Small abandoned quarry on Lewis farm a short distance northeast of Menges Mills, north side of R. R. Average of 2 samples.
6. George Hoke Quarry along Pennsylvania Railroad, a short distance northeast of Menges Mills.
7. Bittinger abandoned Spring Grove Quarry on P. R. R., ½ mile southwest of Spring Grove. Average of 6 samples.
8. J. B. Rebman abandoned quarry, 2 miles west of Thomasville. Average of 2 samples.
9. 3 abandoned quarries of King and Williams, 1 mile west of Thomasville. Average of 6 samples.

	10	11	12	13	14	15	16	17	18
$CaCO_3$	90.00	76.01	56.45	94.90	94.73	92.36	92.98	76.78	68.59
$MgCO_3$	6.03	19.95	30.30	18.75	4.26	5.43	4.99	14.37	26.68
SiO_2	2.81	3.30	1.58	2.26	0.78	1.75	1.53	7.65	3.85
Al_2O_3	0.08	0.34	0.33	0.08	trace	0.35	0.02	0.83	0.11
Fe_2O_3	0.45	0.99	1.21	0.60	0.36	0.04	0.38	0.75	0.66
S	0.024	0.020	0.020	0.020	0.00	0.00	trace	0.00	trace
P	0.023	0.016	0.022	0.014	0.030	0.015	0.013	0.030	0.014

10. Old quarry belonging to Paul Krugg, 1 mile west of Thomasville. Average of 2 samples.
11. Spengler abandoned quarry, ½ mile west of Thomasville.
12. Farm of Robert Bear, 1 mile east of Thomasville.
13. 3 abandoned Gross quarries, 1½ miles east of Thomasville. Average of 14 samples.
14. Farm of Wm. Yost, 1½ miles east of Thomasville. Average of 6 samples.
15. Farm of Jacob Emig, 1½ miles east of Thomasville. Average of 9 samples.
16. Farm of Zach. Louver, 2 miles east of Thomasville. Average of 3 samples.
17. Farm of Wm. Yost, 2 miles east of Thomasville. Average of 3 samples.
18. Farm of Wm. Bott, 2¾ miles west of York. Average of 10 samples.

	19	20a	20b	20c	20d	20e	20f	21a	21b
$CaCO_3$	55.35	55.48	55.91	55.49	83.46	55.71	55.56	55.23	84.25
$MgCO_3$	42.65	42.56	42.38	42.68	11.08	37.64	38.48	42.90	12.87
SiO_2	1.00	0.89	0.71	1.11	4.79	5.18	2.46	0.81	1.90
Al_2O_3	trace	0.44	0.22	0.28	0.18	0.74	0.80	0.17	0.16
Fe_2O_3	0.92	0.51	0.69	0.55	0.56	0.81	0.75	0.78	0.63
S	trace	0.006	0.00	trace	0.109	0.020	0.010	trace	trace
P	0.016	0.012	0.008	0.010	0.018	0.012	0.017	0.020	0.020

19. Farm of Gise & Diehl, 2 miles west of York.
20. Wm. Smyser Farm, purchased by Bethlehem Steel Co., 2 miles west of York. Averages of 6 100-foot holes with analysis every 5 feet. a, b, and c located in east part of property: d, e, and f in west and northwest part.
21. David Bentzel Farm, 2 miles west of York. a, average of 4 samples. b, average of 3 samples.

	22	23a	23b	24a	24b	24c	25	26	27
$CaCO_3$	72.95	78.22	90.22	93.90	99.76	55.51	54.44	70.64	85.61
$MgCO_3$	24.50	20.04	5.85	5.27	trace	41.60	41.10	25.80	4.86
SiO_2	1.17	0.34	3.29				3.70	1.40	7.65
Al_2O_3	0.42	0.05	0.00	0.22	0.06	1.20	0.00	0.06	0.83
Fe_2O_3	0.88	0.51	0.57				0.88	0.64	1.16
S	trace	trace	0.004	-----	-----	-----	0.00	trace	trace
P	0.038	0.018	0.020	-----	-----	-----	0.024	0.022	0.008

22. Farm of Theo. Helb, 2 miles west of York.
23. Farm of Chas. Kurtz, 1½ miles west of York. a, average of 2 samples. b, average of samples.

24. Palmer Lime and Cement Co., 1½ miles southwest of York. a, white and mottled (calico) marble. b, pure white sugary marble. c, gray dolomite. Analysis by company.
25. Property of C. M. Eichelburger, 1 mile west of York.
26. Quarry of Emigsville Limestone Co., Emigsville. Average of 7 samples.
27. Abandoned quarry of East York Co., 1½ miles east of York. Average of 3 samples.

	28a	28b	28c	28d	29	30	31	32a	32b
$CaCO_3$	80.71	97.44	58.41	84.58	78.33	86.98	61.15	56.05	92.70
$MgCO_3$	9.63	1.66	36.77	11.21	14.87	2.17	33.55	42.00	5.00
SiO_2	7.61	0.40	0.91	2.88	5.63	9.21	3.43	1.10	1.25
Al_2O_3	1.04 }	0.10	3.83 }	1.28	0.36	0.72	0.26 }	0.85 }	1.05
Fe_2O_3	0.90 }		}	—	0.80	0.84	0.59 }	}	
S	trace	—	—	—	0.02	0.010	0.006	—	—
P	0.010	—	—	—	0.009	0.024	0.034	—	—

28. York Valley Lime and Stone Co., (farm of W. F. Myers) ¾ mile west of Hellam Station. a, average of 14 samples. Analyzed by Bethlehem Steel Co. b, 30-foot bed extensively worked for lime. c, 20-foot bed of low silica dolomite. d, fair average of run of quarry exclusive of shaly layers. Analyses b, c and d furnished by Company.
29. Benjamin Stoner quarry, 2/3 miles northwest of Hellam Station. Average of 10 samples.
30. Quarry of John Emig, southeast of Hellam Station. Average of 5 samples.
31. Quarry of Beard Lime Co., Wrightsville. Average of 10 samples.
32. Union Stone Co., New Holland. a, average analysis of 35-foot bed of low silica dolomite. b, average analysis of 90-foot bed of high calcium stone. Analyses furnished by Company.

	33a	33b	33c	33d	33e	33f	33g	33h	33i
$CaCO_3$	93.49	64.99	95.47	92.64	94.17	87.52	86.00	94.24	98.04
$MgCO_3$	2.61	6.40	2.53	2.22	4.45	9.29	4.75	2.51	1.86
Insoluble	4.05	26.07	2.26	5.19	1.65	3.17	8.30	2.50	0.82

33. Property of Wrightsville Stone and Lime Co., Stoner's Station. a, conglomerate in quarry; b, shaly layers in quarry; c, in woods near railroad; d, conglomerate near kiln; e, outcrop in field east of quarry; f, near railroad bridge; g, lowest grade conglomerate in quarry; h, darkstone near kiln; i, best stone from main conglomerate layer in quarry.
Analyses 1–23, 25–27, 29 and 31 made by Bethlehem Steel Co.

Quarry of B. Frank Beard, Wrightsville

	1	2	3	4	5	6
$CaCO_3$	95.29	94.53	65.14	97.10	93.32	92.21
$MgCO_3$	—	3.18	32.74	—	3.32	7.10
Al_2O_3	—	{ 1.80	{ 0.44	—	{ 3.10	{ 0.28
Fe_2O_3	—	{ —	{ —	—	{ —	{ —
MgO	0.92	—	—	0.64	—	—
Insol.	0.43	0.49	—	0.32	0.26	—
Ign.	—	—	1.52	—	—	—
SiO_2	—	—	0.14	—	—	0.20
Total	96.64	100.00	99.98	98.06	100.00	99.79

1, 2. White limestone, massive compact and fine-grained. 1 analyzed by M. S McDowell, State College, Pa., 1896. 2 analyzed by H. J. Patterson, State Chemist of Md., College Park, Md.
3. Gray dolomite, tough, massive, coarse-grained. Analyzed by M. L. Jandorf, University of Pittsburgh, Pittsburgh, 1912.
4. Gray limestone, massive, compact and fine grained. Analyst, M. S. McDowell. 1898.
5. Gray limestone, massive, compact and fine grained. Analyst, H. J. Patterson.
6. Same as 5. Analyst, M. L. Jandorf. 1912.

Quarry of John A. Emig, Hellam

	1	2
$CaCO_3$	97.53	97.16
$MgCO_3$	0.94	2.86
Al_2O_3	} 0.18	0.24
Fe_2O_3	}	
Insol.	0.68	
SiO_2	—	0.25
Total	99.33	100.51

1. Gray limestone, massive, compact, medium-grained. Name of analyst not given.
2. Gray limestone, massive, compact, medium-grained. Analyst, M. L. Jandorf, University of Pittsburgh, 1912.

Quarry of Benjamin H. Stoner, Hellam

	1	2	3	4	5	6
$CaCO_3$	99.22	98.53	63.90	96.34	95.35	95.41
$MgCO_3$	0.35	0.22	33.00	2.77	3.14	4.30
Al_2O_3	0.24	0.55	0.54	0.54	0.16	0.22
Fe_2O_3						
S						
SiO_2	0.19	0.50	2.08	0.10	0.18	0.28
Insol. [a]	tr	0.20	0.43			
Ign. [b]					0.97	
Total	100.00	100.00	100.00	100.35	99.90	100.21

1. "Good stone"—gray-blue, massive, compact, crystalline. Analyst, C. H. Ehrenfeld, Ph.D., 2-11-'68, York.
2. "Top rock"—blue-gray, massive, compact, crystalline. Analyst, C. H. Ehrenfeld.
3. "Black"—blue-black, massive, shaly, high in magnesia iron and silica. Analyst, C. H. Ehrenfeld.
4. "Blue stone"—from the surface, coarsely crystalline. Analyst, M. L. Jandorf, University of Pittsburgh, Pittsburgh, 1912.
5. "Gray No. 1"—gray, massive, compact, crystalline. Analyst, M. L. Jandorf.
6. "Gray No. 2"—gray, massive, compact, crystalline. Analyst, M. L. Jandorf.

a. Insoluble here includes combustible matter.
b. Ignition includes water ("quarry water").

Quarry of York Valley Lime and Stone Co., Hellam

	1	2	3	4	5	6	7	8
$CaCO_3$	98.07	97.67	98.00	89.72	98.48	84.70	95.41	95.81
$MgCO_3$	1.41	1.72	1.51	4.60	0.32	12.64	1.82	2.54
Al_2O_3	0.15	0.16	0.05	1.57	0.56	1.12	1.88	0.28
Fe_2O_3				0.56				
SiO_2	0.23	0.23	0.37	1.58	0.62	1.88	0.62	1.88
Na_2O				0.88				
K_2O				0.53				
P_2O_5				0.27				
SO_3				0.20				
H_2O (110°C)				0.22				
H_2O (about 110°C)				4.26				
Total	99.86	99.78	99.93	99.91	99.98	100.32	99.73	100.51

1. Sample taken from entire quarry. Analyst, Westmoreland Coal Co. Philadelphia.
2. Sample taken from entire quarry. Analyst, C. H. Ehrenfeld, York.
3. Sample taken from entire quarry. Analyst, Maryland Steel Co., Sparrows Point, Maryland.
4. Sample taken from the entire quarry in 1910. Analyst, H. C. Demming, Harrisburg, 7-25-10.
5. White limestone, massive, compact, fine-grained. Analyst, M. L. Jandorf, University of Pittsburgh, 1912.

Analyses from quarries near York

	1	2	3	4
$CaCO_3$	87.09	92.59	98.37	87.63
$MgCO_3$	9.39	3.77	0.47	3.94
$Al_2O_3+Fe_2O_3$	0.96	2.04	1.22	1.94
SiO_2	0.88	1.78	0.16	6.04
Total	98.32	100.18	100.22	99.55

1. Sample taken from John Schum and Geo. A. Ruhl, quarry, 1½ miles northeast of York, 1911.

2. Sample taken from H. S. Ebert and A. M. Hake quarry, 1½ mile east of York, 1911. Represents entire quarry.

3. Gray-blue limestone, massive, compact, crystalline from same quarry as 2.

4. Sample taken from the Chas. E. Miller quarry ⅝ mile southeast of York, 1912.

Analyst, M. L. Jandorf, University of Pittsburgh, 1912.

Quarry of P. S. Burgard, 1½ miles northeast of York

	1	2	3
$CaCO_3$	99.34	98.79	98.44
$MgCO_3$	0.21	0.18	0.72
Al_2O_3	0.18	0.80	0.36
Fe_2O_3	0.02	...	...
SiO_2	0.32	0.16	0.32
P_2O_5	0.03	....	....
Na_2O	0.05	....	....
H_2O (110°C)	0.09	....	....
Total	100.24	99.93	99.84

1. White limestone, massive, compact, crystalline. Analyst, H. C. Demming, Harrisburg, 8-15-1908.
2. White limestone, massive, compact, crystalline. Analyst, M. L. Jandorf, University of Pittsburgh, Pittsburgh, 1912.
3. Gray limestone, massive, compact. Analyst, M. L. Jandorf. Pittsburgh, 1912.

Quarry of Emigsville Quarry Co., Emigsville

	1	2	3	4
$CaCO_3$	98.35	96.35	98.09	88.70
$MgCO_3$	1.41	2.08	1.25	9.75
Al_2O_3	0.13	0.15	0.40	0.76
Fe_2O_3	...	...	...	...
SiO_2	0.19	1.13	0.24	0.74
$Ca_3(PO_4)$	....	0.05	....	....
Organic Mat.	tr.	....	....	....
Total	100.08	99.92	99.98	99.95

1. Samples taken from the entire quarry and outcrops to the north and south, 1910. C. H. Ehrenfeld, York.
2. Samples taken from the entire quarry and outcrops to the north and south, 1910. C. A. Jacobson, York.
3. Gray-blue, massive compact, saccharoidal limestone. Analyst, M. L. Jandorf, Univ. of Pittsburgh, Pittsburgh, 1912.
4. Sample taken from the quarry and an outcrop to the north, 1911. Analyst, M. L. Jandorf, University of Pittsburgh, 1912.

Quarry of J. E. Baker Co., New Holland

	1	2
$CaCO_3$	96.00	92.84
$MgCO_3$	2.60	6.74
Al_2O_3	0.20	0.18
Fe_2O_3	...	...
SiO_2	1.20	0.28
Total	100.00	100.04

1. Samples taken from the entire quarry, 1911. Analyst not given.
2. Samples taken from the entire quarry, 1911. Analyst, M. L. Jandorf, University of Pittsburgh, Pittsburgh.

Quarry of York Stone and Supply Co., ¾ mile north of York

	1	2
$CaCO_3$	65.32	87.09
$MgCO_3$	31.23	9.32
Al_2O_3	1.70	1.32
Fe_2O_3	...	...
SiO_2	1.74	2.36
Total	99.99	100.09

1. Gray, compact, fractured, much metamorphosed limestone. Analyst, M. L. Jandorf, University of Pittsburgh, Pittsburgh, 1912.
2. Dark-blue, limestone, compact, massive. Analyst, same.

Quarry of Universal Gypsum and Lime Co., York

	1	2	3	4	5	6	7
$CaCO_3$	-------	99.32	-------	99.52	-------	99.07	-------
CaO	55.56	-------	55.29	-------	48.40	-------	45.77
$MgCO_3$	-------	0.24	-------	0.16	-------	0.38	-------
MgO	0.35	-------	0.48	-------	6.18	-------	8.81
Al_2O_3	0.04	0.04	0.02	0.16	0.07	0.32	0.03
Fe_2O_3	0.05	-------	0.10	-------	0.30	-------	0.27
SiO_2	0.58	0.28	0.14	0.20	0.27	0.24	0.25
Total	55.53	99.98	56.03	100.04	55.22	100.01	55.13
By difference	43.47	-------	43.97	-------	44.78	-------	44.87
	100.00		100.00		100.00		100.00

1. White, compact, high-calcium limestone. Analyses made during 1909, U. S. Geol. Surv., Pittsburgh.
2. White, compact, high-calcium limestone. Analyst, M. L. Jandorf, University of Pittsburgh, Pittsburgh, 1912.
3. Blue, compact, fine-grained, high calcium limestone. Analyses made during 1909, U. S. Geol. Surv., Pittsburgh.
4. Blue, compact, fine-grained, high calcium limestone. Analyst, M. L. Jandorf, University of Pittsburgh, Pittsburgh, 1912.
5. Mottled "calico," fine-grained limestone with patches of dolomite. Analyses made during 1909, U. S. Geol. Surv., Pittsburgh.
6. Mottled "calico," fine-grained limestone with patches of dolomite. Analyst, M. L. Jandorf, University of Pittsburgh, 1912.
7. Average of entire quarry. Analysis made during 1911, by the Bureau of Standards, Pittsburgh.

Quarry of L. D. and Wm. A. Cunningham, ¼ mile south of West York

	1	2
$CaCO_3$	73.60	51.12
$MgCO_3$	20.90	33.06
Al_2O_3	1.44	3.80
Fe_2O_3	...	...
SiO_2	4.00	12.00
Total	99.94	99.98

1. Gray blue limestone, massive compact. Analyst, M. L. Jandorf, University of Pittsburgh, Pittsburgh, 1912.
2. Dark blue limestone, massive, compact, containing much carbonaceous matter. Analyst, same.

Analyses from quarries near York

	1	2	3	4
$CaCO_3$	86.35	70.74	94.52	88.00
$MgCO_3$	8.94	15.21	4.82	9.72
Al_2O_3	1.98	4.04	.37	0.81
Fe_2O_3	...	....	....	0.15
SiO_2	2.44	9.92	.29	1.28
Total	99.71	99.91	100.00	99.96

1. Sample from James March quarry, 2½ miles west of York. Analyst, M. L. Jandorf, 1912.
2. Sample from L. H. Alwine quarry, ½ mile west of Spring Grove. Analyst, M. L. Jandorf, 1912.
3. Sample from J. E. Baker Co. quarry, York. Analysis furnished by the company.
4. Stone from quarry of Medusa Portland Cement Co., 1½ miles N. W. of York, used for portland cement. Analysis furnished by the company.

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